Einstein's Responsibilities for Wave-Particle Duality*

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In his explanation of the Photo-Electric Effect Einstein defines his photons as "energy quanta which are localised at *points* in space" *and* possessed of a frequency $E = h\nu$ at the very same time. ($R\beta\nu / N$ in his text.) Thus we are told that energy is quantized, because rather than a field spreading continuously over a region, "light is *discontinuously* distributed in space". [Einstein, 1965 (1905), p. 368] *Planck's* notion of quantization meant the discrete spectrum of eigen *states* (or eigen frequencies) of a *single* oscillator, sufficient in itself to make quantization manifest. But in order that a photon can make its own 'quantization' manifest it needs *another photon*. Alone it is just a speck in space. In Planck's original it would not be enough, it would not even be relevant, to call cars in a car park 'quantized', mainly because they are 'discontinuously distributed in space'. My aunt and I are thus distributed. Are we.quantized? To Einstein it seems we must be.

Yet, albeit discontinuously distributed at *points* in space, photons have a ...frequency in this new setting! I cannot even begin to fathom how anything localized at a point can have a frequency, but what I do fathom is how Duality sprang forth from precisely this infected womb, now weirdly impregnated by an unlovely hybrid. To get back to QM as it was initially conceived, I reinterpret $E = h\nu$, now $Et = h$, and $p = h / \lambda$, now $p\lambda = h$, as alter-native definitions of quantized *action*, committed to neither waves nor particles. I conclude with what Duality *really* was in the mind of the man so wrongly accused for its introduction: Niels Bohr. Namely, it is but the *side product* of Indivisibility ('wholeness' more frequently in his writings) - not a primitive QM axiom at all.

*** Forwarded from Galilean Electrodynamics; see endnote****

1. QM: A History of Wrong Turns

The physically weird aspects of QM are several: discontinuity, indefiniteness of states during transitions, interacting system non-separability, *i.e.* quantum wholeness, to name the most spectacular of the lot.[1] But there is a further aspect of it, which seems to be weird also in the logical sense: Wave–Particle Duality, namely, the supposition that a micro-system in motion can either be extended as a wave, and therefore large, or localized as a particle, and therefore small, both placed on an equal footing 'prior to measurement'. That is, although actual measurements will respect the 'mutual exclusion' between these two types of motion, realizing either one at the expense of the other, saving us all by the bell, so to speak, still prior to measurement the microsystem could just as well be *either*. That is to say, both. (Or potentially both.)

And not only that: in the forties and fifties, Duality became a shorthand expression for QM itself. And, it goes without saying, a short hand expression of Bohr's 'Complementarity' (CTY) all the more, now obscurely pertaining between waves and particles also. Even in our own times the view still persists that Complementarity appears to have been introduced by Bohr in response to the wave-particle duality, which becomes the wave–particle *complementarity* in his framework. [Plotnitsky, 1994, 68].

Isn't simplicity wonderful? Take the mystery of the century, give it a new name and you are home free. That Bohr is thus delivered in the hands of his enemies as the obscurantist of his times not only is of no concern of this author. Regrettably, he welcomes it: "Wave –particle complementarity is thus defined in *anti*–epistemological terms" [*ibid*] he concludes. Yet before the times, when Bohr was hailed as some sort of a scientific Trojan Horse by 'anti-epistemologists' and deconstructionists, he had spoken very differently: The term 'complementarity', which is already coming into use, may be suited to remind us of the fact that it is the combination of features which are *united* in the classical mode of description but appear *separated* in the quantum theory.[2] [1934, 19]

Here then: since CTY is the combination of features united in the *classical* mode of description, if CTY obtains between waves and particles, waves and particles are united in the classical

[1] *Non-locality is not mentioned, for I do not think that non-locality *is* a quantum phenomenon in the first place, not even officially. The violation of Bell's Inequality leaves us with (at least) two options: [1] QM is causal but not lo-cal, [2] QM is local but not causal. Hence, since standard QM *is* a noncausal theory, it is also local. We must not forget that Bell's primary motivation was to investigate, whether the Bohm version of QM, *i.e.* its "grossly nonlocal character" [Bell, 1966], was mandatory. And the violation of Bell's Inequality shows this, if it shows anything: that it is not mandatory at all. Santos [1985, 251], Brody [1985, 243] and Bitsakis [1990, 333], have shown that even *classical* systems under suitable conditions can manifest non-local properties, a motion which I have seconded. [Antonopoulos, 1999, 54]. Those who hold that non-locality is a quantum property, another wrong turn in its history, more or less confound it with actual quantum wholeness (in Bohr's sense), which latter, however, pertains between measuring instrument and atomic object, and is therefore *proximal*. Hence, is *other* than nonlocal. [Antonopoulos, 1997, 57-61; Antonopoulos 1999, 56ff] But there is no time to go into this matter in detail.

[2] ** Those being, of course, the two action yielding products, Et and pq .

mode of description. This is what a good start has been turned into.

Exegetic remarks alone will hardly justify Bohr's dismissal of Duality as a possible basis of CTY. Logical remarks are required, which will show that Bohr was right in dismissing it or, to be precise, right in never really endorsing it despite all widespread presumptions to the contrary: For the requisite incompatibility of a $\Delta E = 0$ with a $\Delta t = 0$ or of a $\Delta p = 0$ with a $\Delta q = 0$ in QM the additional premise that $h > 0$ is absolutely necessary. But waves, which, as said, are large (extended) and particles which are small (localized) are incompatible *independently* of the premise that $h > 0$ and its truth or falsehood. For the incompatibility between the predicates 'large' and 'small' is warranted in *advance* of the quantum. In short, it is *self-sufficient* and has no *need* of the quantum. This is why, besides, waves and particles are mutually exclusive even in Classical Mechanics. And Classical Mechanics does not contain the quantum. Not quite the story they usually tell us, is it?

This, then, is the state of the business today. And this the state it has been for a century. The very thing, whose internal logic makes it impossible for it to even *relate* to the quantum, and thereby to the quantum uncertainties, Wave–Particle Duality in the flesh, to be the thing hailed as *the* reason behind them, *the* reason behind CTY, *the* reason behind Q M itself. Yet prior to distortion, QM was not about waves and particles at all. It was about plane (infinite) waves and wave packets, which latter are indeed mutually exclusive in ways demanded by the theory. (But I will offer a more coherent alternative to even this.)

So speaking of wrong turns, the introduction of Duality within the quantum scheme was certainly the most decisive, and the most harmful of all. And this is why, though I am fine with Planck, de Broglie and (obviously) Bohr, I have a host of problems with Einstein and his way of doing things in QM (his demand for completeness included). For it was his alleged explanation of the Photo–Electric Effect that started it all. Namely, his idea not just to introduce particles in the radiation, which, let us concede, was inevitable. But to also endow them with a frequency $E = h\nu$, toying with Planck's conception in ways that were hardly consonant or even available in the original.

But as physicists, people tell me, we must take account of experiments. What about the experiments, they tell me, which establish the presence of both the waves *and* the particles? Well, what about them? If the theory is not about waves and particles in the first place, then what good are experiments to it? It would be a different theory, which they support. Hence, experiments are useless, if we are ignorant of the theory. We must first decide, what QM actually tells us (this phrase alone suffices to measure the futility of the task), and only then turn to experiments.

The myth of wave–particle CTY (for I am not saying that Duality per se is a myth), namely, the myth that Duality is a part of the *theory*, when only something vaguely reminiscent of it actually is (de Broglie's relation), is the product of a wrong turn after a marvelous start. The start was Planck's and the wrong turn Einstein's weird interpretation of the Photo–Electric Effect. One that renamed as quanta entities 'discontinuously' localized in *space*. (His words.) By the same standard I and my uncle are also quantized. For Einstein, truly, offers none other. This, I have argued [Antonopoulos, 2009], is a misconception. Planck's quanta (apart from being eigen–states representing eigen–frequencies, hence nothing *like* Einstein's photons), are quantized *levels*. That is to say, discontinuously arranged possible *states* of a system. Of one unique system, I should stress, which, by Einsteinian standards, would not be quantized at all (!), since to him quantization consists in discrete particles scattered in space, and hence needs *many* of these, of which Planck's assumption only needs one. Were *photons* the paradigm of discreteness, Planck's quantization could not even be stated. Fortunately (for all), they are not.

QM is an elegant theory, when done properly, though it can turn out quite grotesque, when not. In what follows will show that, though in the daily practice of most physicists it is always the latter, it is essentially, even if rarely, the former.

2. Quantization of Action

Quantization of action may be concisely derived from its association with the concept of a *period*. [See Darrigol, 1993, 30] If action is "regarded as a periodic function" [*ibid*.] then the state of a dynamical quantity, E or p, can only be mapped over a period; a wave period. If this period is expressed in terms of the frequency, ν, we obtain $E = h\nu$ and so $Et = h$. If it is expressed in terms of the wavelength, λ, we obtain $p = h/\lambda$ and so $p\lambda = h$, as two alternative expressions of minimal action, h.

Stated in more detailed fashion, this idea reveals that the basic quantum relation $E = h\nu$ implies that E, exactly like ν, can no longer be defined *at* an instant $t \to 0$, as was classically assumed, but only over a period $t > 0$, whose boundary instants $\{t_1, t_2\}$ are here given by the overall frequency of this period, ν. Frequency per *se*, of course, cannot be defined at an instant at any rate, since a *repetitive* phenomenon, and hence such that demands a time latitude at least as wide as to allow the phenomenon to (minimally) occur twice, before any inkling, even, of a frequency is to at all suggest itself. The assumption that $E \approx \nu$, *i.e.* the main quantum assumption, then extends the same reasoning to energy. By analogy, p cannot also be determined *at* a point, $q \to 0$, as was classically assumed, but only over a *distance*, whose boundary points $\{q_1, q_2\}$ are correspondingly given by the wavelength of this period, λ.

The notion of the quantum of action results directly from these foregoing considerations. It is *because* E cannot be defined at an instant t $(or\ dt) \to 0$, but can only be exemplified over a period, that the resulting product Et is not arbitrarily reducible to a diminishing value $Et \to 0$, thus yielding a *quantum* of action instead. That is to say, it is because E can only be defined over a limiting period $t > 0$, rather than within a $t \to 0$, that the whole product itself, Et, is placed under the same restriction, yielding a quantum of action, h. In the case that E could be recorded *at* an instant, taking that instant as narrow as we wished, the product Et would be a vanishing quantity for any positive value of E, and then no quantum of action would ever result. The argument pertaining to the product $p\lambda = h$ is an exact analog of the previous, by simply substituting p for E and distances (or points) for corresponding times (or instants).

So, after all, it is *action*, which is periodic, *i.e.* wave like; not 'particles'. In this result Darrigol's introduction is very helpful.

Before departing from this account of the concept of minimal action, it would perhaps be useful to point out the following, important element contained in it, bifurcating the initial principle, as it were. In the conception of quantized action as above understood we can observe that the possible range of values potentially assigned to the energy, E, can vary *continuously*. For any product $Et = h$, another value of the energy, E_1, can be taken as *close* to E as we care to specify, and still yield a quantized unit of action $E_1 t = h$. All we need do is to simply adjust the value of t accordingly, for the new product to still yield the constant, h. Nor, therefore, is there a limit placed upon the diminution of the value of the energy as such, so far as this conception of quantized action is concerned. The quantization of the product $Et = h$ can be satisfied for any energy value whatsoever, provided it is positive. And for any intermediate values we care to introduce or imagine.

But the root of the reasoning formerly presented, the relation $E = h\nu$, when applied in turn to the potential range of energy values of harmonic oscillators, will only yield a *discrete* spectum of permissible values instead. And will yield limiting energy differences between quantized energy levels, and thus minimal, atomic states of *energy*, which latter were nowhere to be traced in the account of action quantization, when circumscribed in isolation of all else and left to its own devices. Despite their contrast, however, both these forms of quantization are individually quite legitimate. (Though some others are not.)

3. Quantization of Energy

When Planck decided to drop the classical supposition, that energy differences[3] during absorption and emission of radiation varied continuously, assuming that they occur in discrete amounts instead, he was *ipso facto* led to also conjecture that energy in the circumstances specified behaved exactly like the frequency. The black body, which was Planck 's physical model of emission, was a cavity. In other words, an harmonic oscillator. This meant that the frequency of a wave, in our case of a radiation, confined within the walls of the cavity, could only increase or decrease by integer values; its eigen–frequencies. Wavelengths enclosed within that cavity could only be such, as to produce a sum always equal to the distance separating the two (parabolic) walls of the cavity. Any other oscillation, the sum of the wavelengths of which turned out shorter or longer than that distance, could simply not exist within the cavity (as a straightforward, mathematical phenomenon). Hence, the sole permissible oscillations within the cavity were one and all integer multiples of one another: The wavelengths, integer subdivisions of the initial wavelength, the frequencies corresponding to them, integer multiples of the initial frequency. All in all, frequencies in a cavity could either rise or drop by discrete, integer values only.

Now add to the previous, known phenomenon, the novel assumption that energy differences during absorption and emission must also rise or drop by discrete, integer values only. What do you get? You get, that the range of fluctuations of the energy values imitate and strictly adhere to the range of fluctuations of the frequency values, both running on rigidly parallel lines. What are eigen–frequencies for the radiation are eigen–values for its energy. Hence, Planck surmised, there must exist an analogy between frequency changes and energy changes, more broadly, an analogy between energy and frequency. Such that their ratio would always have to be a constant; say, $E / \nu = n$ (some invariant number). Or, as history has it, $E / \nu = h$. That was how, roughly, the quantum of action came into being.

4. Quantization of Fields: (i) An Irrelevant Quantization

'Photoelectric Effect' is the name of the phenomenon of shining light of variable frequencies upon the surface of a fluorescent material (of small ionization work), thus causing some of its electrons to leave the material and pass through a conducive medium, in this case an electric cable (cathode ray), suitably equipped with a counter, containing a needle, intended for measuring the energy level of the electric current going through said cable. The photoelectric effect presents itself to us by the following sets of facts:

Fact 1: When the frequency of the incident light rises (*e.g.* from red to blue or violet), the needle of the counter rises in direct proportion, suggesting that the higher the frequency of the light, the greater the energy of the electric current.

Fact 2: *Below* a certain frequency threshold no electric current is produced in the cathode ray at all. The counter needle stays inert at zero.

Fact 3: Below said threshold, the needle remains unaffected, however much we may increase the *intensity* of the incident radiation. (That is, two or three identical lamps shining in the place of one.)

Fact 1 and **Fact 2** immediately suggest, and reinforce, Planck's original law: The energy of the light, and of radiation in general, is exactly proportional to its frequency: $E = h\nu$. Fact 3 is what Einstein bases (??) his 'explanation' upon. Now here is a preview of this explanation, to be complemented below with his own words. Relying on **Fact 3**, Einstein assumes that the inci-

[3] It is customary to present Planck's idea without this crucial word, 'differences'. And thus have it (innocently) assert that "the absorption and emission of radiation occurs in discrete amounts" –just. And if it does, what of it? If the word 'differences' is omitted together with all its related derivatives, what merely follows is that a suitable oscillator will only emit (or absorb) discrete amounts of energy, and none of the intermediate values. Say, 1, 2, 3, *etc*., at the exclusion of intermediate possibilities. This hardly ever amounts to the quantum mystery that it really is, at the end of the day. The oscillator just returns to the environment exactly as much as it absorbs, no more no less. So if it absorbs an integer value, it returns an integer value. What else should it do –and so, what if it does? When, however, it is added that it is actually energy *differences* during absorption and emission, which occur in discrete amounts instead, when, that is, it is realized that energy *changes* by said amounts, there's no going back to classical conceptions, appeased by the former way of speaking. Now changes of *state* must occur discontinuously. Namely, without admitting of a state in–between states and so without admitting of *conservation*, either. And we are suddenly left gazing at chaos or nothingness, right when we were only puzzled just before.

dent ray is not a continuous wave field at all but rather consists of highly concentrated, particle-like units of energy, its light quanta or photons, each one of which is *individually* interacting with a similarly individual electron of the material, thus imparting to it part or whole of its energy, now transformed into kinetic by the electron in question. Since the energy of the incident photon is evidently proportional to its frequency, as both Planck's law *and* the effect in question jointly imply, the energy of the electric current thus produced *is* a function of its frequency, in satisfaction of Planck's initial law and quantum theory. In Einstein's own words:

"Energy quanta penetrate into the surface layer of the body, and their energy is transformed, at least in part, into kinetic energy of the electrons. The simplest way to imagine this is that the light quantum delivers its entire energy to a single electron; we shall assume that this is what happens." [Einstein, 1905 (1965), p. 373]

On the other hand, however, since the effect in question indicates that the intensity of the incident light is idle in the production of these results below the threshold (Fact 3), Einstein relates it directly with the *number* of the incident photons contained in said light. Hence, be they one, two or many, but of a single energy value all, since we still remain below the threshold frequency, when they individually interact with just so many electrons from the material, they no longer affect their (kinetic) energy, thus the energy of the electric current is not in any way affected. In Einstein's own words once again,

Einstein 1: If each energy quantum of the incident light delivers its energy to electrons, *independently* of everything else, then the velocity distribution of the ejected electrons will be *independent* of the intensity of the incident light. [Einstein, 1905 (1965), p. 374]

Einstein 2: On the other hand, the *number* of electrons leaving the body will be proportional to the intensity of the incident light. [*ibid*.]

That is to say, proportional to the number of the incident photons, as implied by **Einstein 1**, since the latter implies a one – to-one correspondence between the two of them. And so we have light quanta, or photons. Why? Essentially, because of **Einstein 2**; the energy carriers in the light are *countable* entities, each imparting its own energy to each corresponding electron. And there being countable, discrete entities in the radiation, "energy quanta localized at points in space" in his words, is what quantization is all about. Why (again)? Because of Einstein's new conception of the *intensity:* The 'number element', as it were.

Now pedantic though this may seem, hard as one may look into the vast stretches of the quantum literature, one will see little (or nothing) mentioned about a quantized *intensity*. One, however, will see plenty of quantized energy. The view that a (so-called) 'wave' is actually a fragmented, (multi) phenomenon of light quanta scattered in space, replacing the classical idea of a uniform, continuous field; namely, quantization as currently understood - is a consequence of its having *this type of intensity;* it is **Einstein 2** in the flesh. So now energy is quantized, because the intensity is! I don't exactly know why, nor why this is actually never *said* (that the roots of quantization a la Einstein is the intensity, not the energy) but, somehow, this seems to be wrong; terribly wrong.

In Planck's conception of $E = h\nu$, radiation is quantized *independently* of its intensity, be it high or low. It is a consequence of relating energy to the *frequency*, and so to the discreteness of eigen states corresponding to eigen frequencies. And, so far (*i.e.* in Planck's model), the frequency itself is *unrelated* to the intensity. Three identical yellow lamps in Planck's model will light the room three times more brightly than a single such lamp. But the frequency of this Planck–radiation hasn't changed one bit. Nor will it, when we change back to a single yellow lamp instead. *Intensity is idle* in Planck's model, without so much as touching energy quantization. But it is very much active in Einstein's model, in ways that raise (at least my) suspicions, (if no one else's).

Let us consider a light ray of the sort Einstein introduces in the photoelectric effect. It has a total energy E, evenly distributed among its quanta or photons as, say, $e = E / n$, where e is each separate photon's energy and n the total number of quanta contained in it. Since containing spatially separable, discrete and individually countable photons, rather than being a field, this light ray is quantized, he says. It is quantized, *even if it remains at that particular energy level* E for as long as we wish to specify. Namely, at a unique energy level. And one may here be interested to know, how exactly is the principle of energy quantization to be meaningfully introduced for the cases of *stable* energy values (or states). Planck's law, exploiting eigen frequencies (and $E = h\nu$), only works when at least one *more* such frequency is juxtaposed to the previous. (And so one more eigen state.) Only then can one assert that the second (and the others) are integer multiples (or sub-multiples) of the first. A *solo* eigen frequency is an absurdity and a contradiction in terms. Yet Einstein's quantization can 'quantize' the *self-same* eigen state.

Consequently, 'quantization' in the form of just so many energy quanta [Einstein, 1965 (1905) p. 372], admitted at a possibly *stable* collective state, is a gross misnomer. Light may be consisting of just so many photons, for all we know. But to call those photons 'light quanta', implying that *this* is what quantization, and discontinuity, are all about, is to say something not only irrelevant but, indeed, pernicious. (Which is no surprise, really, considering its derivation by a notion *other* than energy altogether, *i.e.* the 'intensity' as Einstein apparently conceived of it.) I proceed to show how irrelevant and how pernicious this was.

For the past decade I have been investigating the possibility of applying basic quantum principles for offering a cogent reply to Zeno's paradoxes of motion. One of them [Antonopoulos, 2007] has received the following negative response by Prof. Joseph Alper:

"Zeno's paradox cannot be explained by quantum mechanics. More strongly, the paradox cannot even be *stated* in quantum mechanical terms. Einstein did not reject discontinuity. In fact, it was Einstein –*not Planck*– who invented the idea of the photon and fully realized the discontinuity it entailed." [October 11, 2006][4]

[4] The argument that follows is a summary of the full-scale presentation I have given in [Antonopoulos 2009], including my reply to Prof. Alper. It is here repeated for reasons of preserving the coherence of the work in hand.

It is well worth the trouble to take a brief look at how fully indeed has Einstein realized the discontinuity 'entailed' by the photon. This is what he says about photons:

"Phenomena connected with the emission of light are more readily understood if one assumes that the energy of light is discontinuously distributed in *space*. In accordance with the assumption to be considered here, the energy of a light is not continuously distributed over an increasing *space* but consists of a finite number of energy quanta which are localized at *points in space*." [Einstein 1965 (1905), p. 368]

All of a sudden we are being told that the mere fact that two physical objects are separated with *space* stretching between them, makes them 'quantized'. In fact, this is precisely what Einstein means here, as can be amply verified by his extensive account of (his 'fully realized') sense of discontinuity, as presented in the book he wrote together with L. Infeld. There he simulates the idea that energy is a quantized magnitude by pointing at grains of sand and, even, miners coming out of the mine! [Einstein, Infeld, 1959] Are we to conclude, then, that a flock of birds is a quantized magnitude, because it consists of birds that are 'discontinuously distributed in space'? And that this flock of birds is "not continuously distributed over space but consists of a finite number of birds, its quanta, localized in points of space"? Is this the 'full realization' of Planck's subtle conception, this facile, unprocessed, *pictorial* understanding of quantization?

It may be true, exactly as Einstein and Infeld remarked, that "…it would be absurd to say that the number of miners increased by 3, 273 since yesterday" [*ibid*.]. Yet absurd, because miners increase by whole numbers *necessarily*, the other alternative being a logical impossibility. And so it is itself an utter triviality. But when the same happened to energy, it was the anomaly of the millennium, and the other alternative, its continuity, by contrast, exactly what everyone demanded. Einstein's comparison is a farce.

And the confusion is simply monumental (for Einstein *or* his belated defender). Einstein's quantization requires *many* of a thing to even manifest itself. Namely: many photons. Were there but a single photon in view, nothing would ever be quantized in lack of another of its kind for comparison. But still a single, unique, harmonic oscillator can suffice in all its solitude to display in full all the requisite properties of quantization. A second of its kind is essentially redundant for the task, for it will but do the same. But a solitary photon is neither quantized nor not–quantized either. It is just a speck in space.

To appreciate the full extent of this '(full) realization' of the notion of discontinuity, Einstein's *or* Prof. Alper's, consisting of the *classical* picture of material bodies lying scattered here and there in space, consider the following example. A photon-emitting source is connected with a timer, which controls their emission at calculable intervals of our choice. A certain initial interval t is succeeded by a second, $t/2$, a third, $t/4$, and so on. Then, given that the speed of photons is a constant, to these decreasing intervals of emission will correspond shorter and even *shorter* distances separating every photon from the next. Then, if the interval between a certain photon and the one succeeding it, is reduced to a $t \to 0$, their distance will be a vanishing quantity no less.

Now compare this result with what is indeed real and full quantization. When de Broglie re-obtained Bohr's quantum conditions as higher harmonics of the fundamental orbit, directly applying Planck's logic of standing waves to it, thus identifying each discrete electron orbit with a particular eigen–frequency, the orbital distances thus resulting were *fixed, immutable and irreducible*. And not a potentially vanishing quantity separating one light 'quantum' from another, as it was with photons before. And to presume in the case of such orbital differences that they could be shorter (or longer) than the mathematics of harmonic oscillation permits and determines, would amount to contradicting $E \approx \nu$ and, thereby, quantum theory as such.

This then is what QM is turned to: a marketplace type of classicism whose results, most peculiarly yet most deservedly, such as Duality and, worse, Non-locality, ironically spring from the ideas of the very men who would've dreaded them the most: Einstein and his descendants. A persistent sort of instinctive, narrow sighted, classicism digging its own grave. For Planck's postulate, as being confined to discontinuously structured energy *levels*, namely, entities not scattered in space but changing through *time*[5], though truly non-classical, still such as makes no room for its grotesque spatial caricature, 'the photon', a thoroughly spatial notion, if there ever was one. And, once the photon is introduced, then, since $E = h\nu$ cannot be coherently severed from the total picture, the *photon* must now assume it to match the theory, thus leading to Duality –again a spatial notion– and, thereby, to all the havoc caused by Non-locality, of which the former is, of course, the distant ancestor. All this, because Planck's discontinuity, especially as developed by Bohr, was too unpalatable to some and had to give its place to the only 'safe' alternative which would not spook them. The photon. The spook has now come back with a vengeance.

It goes without saying, that when I tried to apply quantum discontinuity to Zeno's paradoxes, I had the latter discontinuity, Planck's, in mind, which is rigid and irreducible, offering Zeno's immobilized Runner his first stepping stone. And not Einstein's pseudo–discontinuity between merely *spatially* separate objects, which we can shorten at will or eliminate entirely, by simply making them touch, which therefore is useless to the Paradox. A discontinuity whose very existence Prof. Alper is ignorant of (or wants to know nothing of) as late as 2006, thus concluding that Zeno's paradoxes cannot even be *stated* in quantum terms. If his 'Einstein's full discontinuity' is between two objects merely standing apart in space, much as I am "discontinuous" with my aunt, really, then *of course* it is useless for handling Zeno's paradoxes. The problem is that it is all the more useless to Prof. Alper, Einstein and, sadly, quantum mechanics itself.

[5] See D. Bohm's account: "Energy appeared to have a certain atomicity *both* in the form of light quanta *and* in the form of discrete, allowed energy levels for matter". [Bohm, 1967, 78]. Which distinguishes between the two. And it is clear that it is the latter, the true quantization, which Bohm is mainly concerned with. [See Bohm, 1985, 128]

5. Quantization of Fields: (ii) Wave–Particle Duality

I shall state my point here briefly first. People claim that de Broglie's relation $p = h / \lambda$ is the epitome of Duality. The p is the particle property and the λ is the wave property, they say. In saying this they forget that *it is by means of* λ *that we determine* p. Namely, by representing the system as a wave (in fact an infinite wave; whence loss of position, the *real* particle property). Therefore, p should be the *wave* property in this relation. Not the particle one. Still once again tradition has it otherwise:

"The energy and momentum, E and p, are concentrated in the *particle*, and the frequency and wave number are defined by the wave." [Rosenfeld, 1961, 384]

This is a great feat indeed, accomplishing the impossible. Although the energy and the momentum are concentrated in the particle, they are still defined by the wave. Which (I hope!) is something *other* than the particle; though not other than the wave. They have to be, if $E = h\nu$, or $E \propto \nu$ is not to be contradicted. To Rosenfeld's untroubled complacency of those times, that the energy is concentrated in the particle, I could also quote another far more recent account, (correctly) identifying it with the *wave*:

"This simple Planck relationship between energy and light frequency in effect says that energy and frequency are the *same thing*, measured in different units. [Coveney & Highfield, 1991, 113] And D.M. Mackay, a contemporary of Rosenfeld's, whom the latter would have done well to read, in one of the best papers written on Bohr in the late fifties speaks of 'the empirical *identification* of energy with frequency'. [Mackay, 1958, 111 and passim]. But if energy and frequency are the same thing, and frequency the *wave* property, then energy should be concentrated in the wave. Hence, not in the particle. How then it is concentrated in the particle, where Rosenfeld detects its presence, is one of the things that will forever remain a mystery to me, although I have acquired a touch of immunity to it, due to long exposure. Even an authority such as C.A. Hooker has had a hand in this muddle, even if only temporarily:

"There is a deep going connection between the *particle*–like energy and momentum and the frequency and wavelength of the corresponding wave, namely, $p = h / \lambda$ and $E = h\nu$." [Hooker, 1972, 74]

Ambiguity and all that notwithstanding, a wave corresponds to *what?* Yet what was to Rosenfeld a way of thinking (it cost to Bohr a lot to have people like him as his followers), to Hooker was only a fleeting inadvertence. Later on in the same work he manages to say the right thing (which was what opened my own eyes for the first time):

"If the quantum relation $p = h / \lambda$ holds, then the momentum, p, can only be determined in the latter, *plane wave* case, where the spatial location, q, is completely indeterminate." [*Op. cit*. 219].

And now we see the light. The momentum, p, is precisely determined only in the plane wave case, as explained in my opening paragraph. But if the momentum is determined by the wave, indeed the *sine* wave, why say at all that p is the *particle* property? Is not p in all instances the variable invariably determined by the wave? The p should therefore be the wave property. Not the particle one. Particles are still missing in this scheme.

And not only that: read above once again, and see the converse of it: "...where the spatial location, q, is completely *indeterminate*" it says. Precisely. But is then not spatial location the particle property? It must be, if only by elimination, since waves are the very negation of a sharp location altogether. This is all straightforward quantum reasoning for decades now. But if the spatial location, q, is completely indeterminate, namely completely excluded, sweeping the particle together with it, whenever p, the momentum, is determined, how can p be the particle property? Is it not the particle, which was just now excluded in this momentum determination? Presumably. But then, there is *no particle in sight*, when the momentum, p, is thus determined via $p = h / \lambda$. In either of the two ways, de Broglie's $p = h / \lambda$ can make no *room* for particles, as neither could $E = h\nu$ before it. It only speaks of waves (and, as Hooker's passage implicitly indicates, of wave packets also).

To sum up: (a) the momentum component of $p = h / \lambda$ can only be determined by means of a wave. Therefore, thus far the momentum is the wave property, if it is determined (only) by the wave. (b) In addition, the momentum is determined by an infinite wave (a unique λ value). This method renders the notion of an exact location completely inapplicable. But then the notion of a particle, which alone is connected with an exact location, is completely inapplicable no less. Yet the value of the momentum has not been taken as completely inapplicable in this process at all. On the contrary it has been taken as completely determinate by *means* of the wave. That is to say, by something other than the particle; though, surely, not other than the wave. Hence, in de Broglie's quantum relation $p = h / \lambda$, whatever he or anybody else may have to say about this, *the momentum is the wave property*. And then, since only h is left in it, which is neither wave nor particle but a unit of action, and since λ is certainly not the particle property, de Broglie's $p = h / \lambda$ says nothing about particles *at all*. There is no such thing in it:

"In the particular case of entities endowed with mass (such as electrons) one group of variables, *i.e.* position, describes the *corpuscular* aspect, while the group complementary to these, *e.g.* momentum, describes, as can be *seen from de Broglie's relation*, the *wave* aspect." [Bunge, 1955, 2]

Quite. But since the corpuscular aspect is now equivalent to the position, of which de Broglie's relation says nothing in any event (only its Fourier treatment can do that, in regard with wave packets), de Broglie's relation says nothing at all about particles. It only speaks of waves and/or, via Fourier, of wave packets. If there *are* particles besides the waves, this is the business of a different theory. Not QM. For that matter, if there are such particles, it is goodbye QM. For since $p = h / \lambda$ says nothing about them, and since its Fourier Expansion is a mathematical analysis of *waves* (or wave packets), likewise saying nothing about them, the resulting uncertainty $\Delta p \Delta q \geq h$ cannot even *apply* to particles. And hence, if there be any such, they could well violate it. Again, not quite the story they usually tell us, is it?

6. Putting Coherence Back into QM

When I present arguments such as the one above, this is what people usually ask me: "But then, what about p, which implies the presence of a particle?" So *that's* the problem, then, is it? *That's* the difficulty. That if p should signify the presence of a particle –apart, that is, from the fact that it does no such thing–, all we *then* have to worry about, is not how this particle can have a wavelength, nor how, when this wavelength is uniform, this particle becomes an infinite wave, but, indeed, how we are to interpret p, if it does *not* signify a particle after all! *That's* the problem to solve, and not all these other deadly absurdities. You have shot me in the stomach and all I care about is the holes in my dinner suit.

Well, I don't have to explain what p is in de Broglie's relation, do I? It was not my idea in the first place. If it happens to contain a p implying a particle, which however is subsequently nowhere to be found, it is hardly *my* problem, for saying that it cannot be so found. But I will answer just the same, not because the enquirers are entitled to an explanation, having made a mess of everything, but because QM deserves it: $p = h / \lambda$ is about action.

Viewed as $p\lambda = h$ it says something quite parallel to $Et = h$, as interpreted in my opening Section: Correspondingly with E in $E = h\nu$ or $Et = h$, *viz.*, when energy could not be defined in an instant, but had to be mapped over a wave period of a frequency ν, so now p, the momentum, analogously cannot be defined *at* a point location, $\Delta q = 0$, but only over a distance, whose boundary points $\{q_1, q_2\}$ are given by the *wavelength* of this period, λ, as before its temporal boundaries were analogously given by $\{t_1, t_2\}$. If you state minimal action in terms of the frequency of the wave period, you obtain $Et = h$. And if in terms of the wavelength of the said period, you obtain $p\lambda = h$.[6]* Hence, all that $p = h / \lambda$ says in this form, really, is that in QM the momentum cannot be conserved *locally*. But can only be applied rigorously *beyond* the boundaries of a limiting distance, λ (or q). And in this interpretation there are neither waves, nor particles, nor 'wavicles' nor 'partiwaves'. There is just minimal action.

The universalized fallacy that, somehow, QM is about waves-and/or-particles is the off-spring of Einstein's catastrophic "explanation" of the Photo–Electric Effect, as shown in the relevant Section(s). Consider the following reasoning: E is $mv^2/2$. And λ, via $Vw = \lambda\nu$, is V/ν. By substituting appropriately in $E = h\nu$ we then obtain: $mv^2/2 = hV/\lambda$. This in turn is $mv^2/2V = h/\lambda$. This, in turn, is $mv^2 = h/\lambda$ and this, finally, is $p/2 = h/\lambda$, namely, a relation hardly unlike de Broglie's own, since $p/2 \dashv p|$ in absolute values. In short, $|p| = h/\lambda$ is *contained* in $E = h\nu$ and, so far as I can see, it is the contrary of this that should be peculiar.

[6] I have extensively argued this point in Refs. 2, 428 ff. and 3, 232. Incidentally, it is clear from these formulations that the Et and pq uncertainties already announce themselves for periods sooner than t and distances shorter than λ.

Now if $p = h/\lambda$ did contain a duality, since it *is* itself contained in $E = h\nu$, then $E = h\nu$ would contain a duality. But since there is no wave-particle duality to be found in $p = h/\lambda$, as established in my Section 4, none should be validly postulated in $E = h\nu$ either, from which it can be directly derived, no further premises added. And it was none such that Planck ever postulated, to begin with. For the sole reason for imposing Duality on $E = h\nu$ was Einstein's 'me here, you there!' conception of quantization, and thus its extension over photons, now having a frequency *and* a sharp localization in space. Then de Broglie's $p = h/\lambda$ [7] only seemed as the most natural extension of the previous idea.

By contrast, I contend that there is no duality inside a wave–field, none, that is, so far as these fundamental quantum relations go. Which is not to say, that there are no particle–like concentrations inside such a field *per se*. That is., it is not to say that there are no such particles in the world. It is only to say that, if there are, they are not so because of *quantum* principles - and that, if there, they can even make trouble for these principles. (As remarked, they would not obey the Fourier Expansion of $p = h/\lambda$; *i.e.* $\Delta p \Delta q \geq h$!) Wave–Particle Duality is not a part proper of QM, though it could be, if you like, a side product of sorts, an oddity of Nature extrinsically attached to it.

You feel that this proposal is too vague, or too arbitrary to justify? Think again. Its support is actually right under your eyes. It has been offered already. Just look at Einstein's *undeveloped* explanation of the Photo–Electric Effect, the one he could have pursued but chose not to, incoherently rejoining what he himself had separated. And look, of course, at Fact 3 itself of the Effect. Intensity in his account, *and* in the message of Fact 3 of the Effect, is *other* than the Energy, right? Hence, since $E \approx \nu$, Intensity is other than the energy–frequency fusion altogether. Namely, other than QM personified. If Intensity *stays* distinguished from the Energy, QM stays a theory liberated from particles within the waves.[8] If this is what Einstein came so close to

[7] De Broglie derived $p = h/\lambda$ from $E = h\nu$ *plus* $p = E/c$, the photon's momentum (from Relativity). I have no reason to dispute his reasoning, though I do wonder what QM might have been like, were he to derive it from the former premise alone, and without taking recourse to Relativity (of all theories!). In any case, *I* did, though hardly antagonistically. Just for showing how closely these two principles, $E = h\nu$ and $p = h/\lambda$, are linked, *without* the help of Relativity.

[8] It's not like we've run out of proposals. The Bohm – de Broglie idea of the pilot–wave, for instance, is not too unlike what I'm suggesting. It's just that they keep both aspects *within* QM, while I'm suggesting that the particle aspect does not really belong there, and could be treated separately. Then there is Bohr's answer, no longer even discussed in our day, which reduces both aspects to quantum indivisibility. Briefly, an indivisible thing will only manifest *undivided aspects of itself.* So, if it is to satisfy a *pair* of predicates, P1 and P2 , and respond affirmatively to both, it can only do so in its *entirety*, and so only in succession. Hence, will respond as if being *all*-P1 in the first attempt and as if all-*P2* in the second, which two accounts conflict with one another. This is indeed what Duality ever was to Bohr: a side product of indivisibility, namely, a *derivative* situation.

saying, but somehow never managed to, then this is the thing (and perhaps the time) *to* say for him. That, I think, should set it straight.

7. For the Sake of Historical Fairness (End)

What sort of a side product it is will be the task of this, my concluding Section, to determine. You have problems with Duality? Tradition goes: Look no further; Bohr is the ideal scapegoat. *He* has done it all. So it's time to set the record straight, if my initial quotation hasn't. ("Complementarity is a relation between concepts *united* in the classical mode of description and *separated* in the quantum," it went. The definition *excludes* waves and particles as its recipients. It's not his fault that people cannot read. Nor his, that his persecutors foist them upon CTY, if to at all lay the blame on him.) And once his (metaphysical but elegant) position is truly understood, it will also become apparent that it is not all that extrinsically attached to QM after all. It has its own place, provided it is *kept* in its place. Wave–Particle Duality, therefore, in Bohr is nothing but a second order consequence of Indivisibility. Which is to him the sole authentic quantum property:

> "The universal quantum of action expresses a feature of wholeness that prevents the distinction between observation of phenomena and *independent* behaviour of the objects." [Bohr, 1958, 98]

This immediately leads to the "difficulties in talking about properties independent of the conditions of observation", such as "material particles producing interference effects" [*ibid*]. It is clear that the "material particles producing interference effects" is a situation *attributed* to the passage right above it; *i.e.*, to the wholeness of the quantum of action. This 'duality' emerges because of:

> "the impossibility of any sharp separation between the *behaviour* of atomic objects and their interaction with measur-ing instruments." [Bohr, 1958, 39–40]

The whole idea from beginning to end is epitomized in the following way:

> "Phenomena like individual, atomic processes, due to their very nature, are essentially *determined* by the interaction between the objects in question and the measuring instru-ments. [Hence]
>
> "No result of an experiment concerning [such] a phenome-non can be interpreted as giving information about inde-pendent properties of the objects, but is inherently con-nected with a situation in the description of which the measuring instruments interacting with the objects also enter essentially. [To conclude that]
>
> "This fact gives the *straightforward (!)* explanation of the *apparent* contradictions which appear when results about atomic objects are tentatively combined into a self– contained picture of the object." [Bohr, 1958, 25–26]

Thus, the contradictions emerge due to the 'wholeness' formed between the atomic object and the instrument that observes it. Suppose an indivisible quantum of energy is to be transferred from the former to the latter. During such transfer one would tend to suppose that this quantum should belong *partly* to the object partly to the device. But that would amount to *subdividing* the elementary quantum. The latter cannot be thus distributed among them because it is itself indivisible and non-distributive. Bohr's unique (and largely misunderstood) reply here is that, during the transfer object and device become *inseparable*; otherwise, the quantum will be divided.

And it is due to this their inseparability, that the atomic object emerges as 'different to itself' in two distinct measurements. For if the atomic object becomes indistinguishable from its measuring devices, then the atomic object will appear as different to itself as the one device observing it will differ from the other. These are the apparent contradictions Bohr speaks of above. They are not primitive but are, as I said, a side–product of Inseparability. Duality (the apparent contradictions) are there, because Wholeness is there first. And they but result from our own attempts at subdividing the phenomena. This is all that Duality ever was to Bohr. Namely, a *derivative* situation and not a primitive quantum axiom, as has been doubly proved in previous Sections. (Remember; de Broglie's $p = h / \lambda$ contains no duality.) Indivisibility alone is the *non plus ultra*, the rock bottom of his interpretation. And there is nothing 'dualistic' about Indivisibility. Bohr is simply a modern day Atomist.

So life is funny. And quantum theorizing is all the funnier! The quantum dualist to end all quantum dualists, if tradition is to be believed, Bohr, turns out a quantum *monist* in the end. And the quantum classicist to end all quantum classicists, Einstein, was the man who first assigned a frequency to "energy quanta localized at points in space". And where this time *both* of these truly contradictory features are presumed as original and primitive in his account of the Photo–Electric Effect. But having witnessed the ways and customs of quantum theorizing for the third of a century by now, I am no longer susceptible to being surprised. But I am not susceptible to keeping quiet in the face of injustice, either.

[For details see Antonopoulos, 1996, 230ff and, of course, Bohr himself in 1958, 25-6, 39-40, 98] Anything, really, rather than say that the particle is the other side of a wave.

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**The Editor of both this NPA Proceedings issue and the journal Galilean Electrodynamics (GED) chose NPA in favor of GED for this paper because it is cultured, amusing, and accessible to a wide audience. It has more warm chuckles than cold equations. Antonopoulos is a professor, and as you read this paper, you can imagine him walking back and forth before his class, engaging them in a sort of a game, making them laugh, and making them think. Really think. Antonopoulos is quite right to worry about the photon. Can it have a definite energy, and hence a definite frequency? Maybe so, but one is justified in worrying about this. After all, it seems inconceivable that the photon can have a definite *wavelength*, since it certainly has *finite* energy, and so cannot extend infinitely in space, and so cannot have a definite wavelength in the same way that an infinite plane wave does. This issue relates to my own NPA paper, "Maxwell's Maxima" from Storrs 2009, Proceedings of the NPA 6 (2) 374-382 (2009). My idea there was a photon that has some natural history to it. It starts as an $\mathbf{E},\mathbf{B}$ pulse dumped by a source, it evolves according to Maxwell's equations into a wavelet, thus developing wavelength, and then it regresses back to an $\mathbf{E},\mathbf{B}$ pulse, in which form it can be accepted by a receiver. It has no wavelength when it is emitted, and it has no wavelength when it is absorbed; it has a wavelength only while in full flight, and even then only approximately. The present paper by Antonopoulos reinforces my feeling that more work along such lines is needed. CKW