Oh photon, photon; whither art thou gone?

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Appeared in: *Proceedings of SPIE* **5866** 112-118 (2005).

ABSTRACT

A survey of the historically most widely considered 'paradigms' for the electromagnetic interaction is presented along with the conflicts or defects that each exhibited. In particular, problems derived from the concept of the 'photon' and Quantum Electrodynamics are emphasized. It is argued that a form of direct interaction on the light cone may be the optimum paradigm for this interaction.

Keywords: photon, Quantum Electrodynamics, charged particle interaction

1. THE DILEMMA

Physics theories comprise at least two elements: a mathematical model, and a "paradigm." The former encodes the regularities of the phenomena of interest, while the latter provides visual and verbal support for thinking and talking about the phenomena covered by the theory, and, of course, motivation for setting up calculations. Theories about the interaction of charged particles (under circumstances, known as: "light") follow this pattern.

In the case of light, in all its variation of scale considered thus far, from radio to gamma waves, the mathematics seems to be largely in order, al least as far as the needs of radio, optical and electronic engineering are concerned. On the other hand, all paradigms proffered so far throughout history for light, have been found wanting. These include:

- WEBER's instantaneous direct interaction (essentially NEWTON's gravitational force scaled to the strength of electrostatic force). This paradigm was unable to accommodate all dynamic interaction; e.g., magnetism.
- HUYGENS', FARADAY's, LORENTZ' and MAXWELL's waves. As it is now clear that there is no medium (aether), electromagnetic waves, it seems, can be no more than mental representations for terms in a FOURIER series decomposition of the full mathematical expression for the interaction. There are several recognized defects endemic to this paradigm including the infamous divergency of the self energy of the electron (in many guises), "run away" solutions, preacceleration, etc.
- SCHWARZSHILD's delayed direct interaction, or WEBER's direct interaction evaluated so as to take the time-of-flight of electromagnetic signals into account. EINSTEIN criticized this paradigm because it did not attribute reality to advanced interaction, which, he held, is a valid solution to MAXWELL's equations.
- FOKKER's mean of advanced and retarded interaction. This paradigm has been faulted for not leading to integrable equations of motion, not to mention the philosophically repugnant concept of "advanced interaction."
- EINSTEIN's "photon." Although very popular at the moment, this paradigm leads to a number of contradictory concepts with respect to interference and severe conflict with General Relativity (more below).
- Second quantized fields. A formalistic elaboration of the photon paradigm; more of a calculational algorithm than a real paradigm.

In addition to the historically well known, but not always emphasized, difficulties with each of the above paradigms, there is a similar set of objections concerned with Special Relativity (SR). It is clear that SR is essentially an application of the fundamentals of electrodynamics; this follows directly from the fact that the core of SR, the Lorentz transforms, contain as an ineluctable parameter, the velocity of *light.* It is not, therefore, unreasonable to speculate that an optimal paradigm for light might render the counter-intuitive aspects of SR less opaque.

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2. PHOTONS AND THE QUANTIZED RADIATION FIELD

The photon paradigm won advocates by virtue of the simplicity of the motivational imagery it provides for the conservation of energy and momentum involved in calculating e.g., COMPTON scattering, and its role in the derivation of the PLANCK blackbody spectrum. In the meantime, is has also acquired critics, because it fails to give a coherent image for interference, as evidenced by the long dispute, to and fro, over whether a single photon can interfere only with itself, or also with other photons.

By far the most pervasive selling point for the photon notion, nevertheless, is the empirical fact, that at very low intensities, radiation in the visible portion of the spectrum is seen to be absorbed always at a single point. This is an artifact, however, of the detection process in this region of the spectrum, which exploits "photo detectors" that convert whatever visible radiation is, to an electron current. Obviously, as an electron current consists of countable electrons which are individually lifted into the conduction band of the detector mass, no matter how radiation arrives, an observer restricted to 'seeing' only the photocurrent and limited to inferring the character of whatever stimulated it, is in no position to pass final judgment on the character of the stimulus, in this case, the incoming radiation. Therefore, the majority of the evidence for photons is intrinsically indeterminate.

3. VACUUM FLUCTUATIONS, THE SIGNATURE OF QED

Intimately connected with these issues is a parallel dispute on just how necessary the whole concept of quantized radiation is in fact. Supporters of the so-called neoclassical theory in which matter is quantized but radiation not, have managed to accurately explain too many quantum electrodynamic (QED) effects to allow writing off this line of analysis out of hand. Moreover, their reasoning offers some support for the paradigm proposed below.

The customary approach to quantization of the electromagnetic radiation field leads to the conclusion that there exists a finite ground state with minimal energy, regardless of the existence of charges. As there are no charges to attribute this state to, it is logically attributed to the 'vacuum,' and discussed as if it had nothing to do with (charge carrying) matter, but is virtually a property of (quantized) 'space' itself. Naturally, this evokes the question: is the energy in the ground state 'real' or just a formalistic device? If the later, it should appear in the mathematical formalism in just such a way that it requires no physical interpretation, or even precludes it altogether. There are many, however, who argue that the ground state actually is the *physical* cause of phenomena, namely: spontaneous decay, the anomalous magnetic moment of the electron and the Lamb-shift, among others. Indeed, calculations of these effects predicated on this presumption have been so successful, that this view is quite credible, and text books commonly cite this fact as evidence of the fundamental rectitude of QED.

On the other hand, proponents of what has become known as the "neoclassical theory" (NCT) found that a judicious reordering of the terms involved in calculations allows an interpretation of these phenomena in terms of a "source theory" which considers *all* radiation fields as derived from source charges. That is, in plain text: vacuum fluctuations are *not* necessary to explain physical consequences; their use in QED is actually just a device which explains these effects *as if* there were such fluctuations.[1]

As an historical matter, NCT was depreciated in the early 1980's largely on the basis of what were taken then as two capital deficiencies. One of these pertains to the phenomenon of 'quantum beats,' which was thought at that time to be correctly describable only by QM.[2] It was taken that NCT predicted beats for the case in which two excited levels decay to a single lower state, which is both not observed and not predicted by QED. This writer disputes this argument, however, on the basis of the existence of a model of the experiments fully in accord with NCT, thereby overturning this as an argument against the validity of NCT.[3]

The second large issue speaking against NCT at that time was the then new experimental results from CLAUSER's group on EPR/BELL type experiments. Although this issue appears not to have been taken up further in the mainline literature, JAYNES himself eventually identified the *lacuna*[4] (See below). Thus, in sum, at the present time there are no unrefuted arguments standing against the NCT.

In view of the current fashionable topics of quantum computing, teleportation and the like, the above statement probably will elicit sharp protest. Proponents of these phenomena, however, have yet to respond to a very elementary and fundamental observation: these phenomena are all described in terms of the algebras of polarization or q-bit spaces, which, unlike phase and quadrature spaces, do not have 'quantum' structure. This observation is supported by the fact that whatever noncommutivity, if any, is evident in polarization or q-bit space, is there because of geometric considerations (essentially

the $SO(3)$ structure of rotation on a sphere) and not because of HEISENBERG Uncertainty, as is the case for quantized phase and quadrature spaces. (Note that for the latter spaces, noncommutivity is an *option*, whereas for the former, it is a geometric ineluctability.) The point here is, that if at all valid, the essence of these phenomena require *no* QM at all for their description, not to mention QED. These effects, from this viewpoint, simply can play no role in the dispute over the necessity of QED.[5]

4. STOCHASTIC ELECTRODYNAMICS: RETROGRADE QED?

Stochastic electrodynamics (SED) is an attempt to rationalize quantum mechanics (QM) by turning QED on its head. This is done by reversing the sequence of the steps in reasoning underlying QM, i.e.,: starting from QM, one eventually concludes that there exist vacuum fluctuations or a finite ground state of the electromagnetic radiation. For SED, one starts from the basic assumption that there exists a classical, random, background field with the power spectrum of the QM ground state, and tries to show that phenomena otherwise predicted only by QM, result. The origin of the SED background has been justified in two ways. One, is that it is simply admissible initial and boundary data for determining solutions to MAXWELL field equations, physically it just emerges from infinity; the other is that it is the average of all interaction with other charges in the universe, and is the dynamic equilibrium of all these separate contributions. In either case, it is argued, it is 'visible' as the force that holds up atoms and otherwise is the source of all specifically QM phenomena.[6]

There are two main streams of SED development; one tries to explain QM effects in terms of the stochastic nature of this background, and, in one way or another, calls on some analogy with diffusion processes. It takes certain inspiration from the formal similarity of the Schrödinger equation, having a single time derivative, with the diffusion equation which also has only a single time derivative. The other line of analysis is based on the observation that the single time derivative in the Schrödinger Equation is accompanied by a factor of i, which is for the mathematics in this application equivalent to another time differentiation, so that any analogy with diffusion processes is essentially illusory. This disappointment is compensated by other arguments to the effect that the background can be used to motivate a physical rationalization for DE BROGLIE's pilot waves, thereby bringing the story into the domain of wave phenomena.[7]

It is especially interesting that the two rationalizations for the existence of a SED background field parallel, to some extent, the two approaches to QED, with source theory having virtually a direct link to the dynamic equilibrium model. In any case, however, both rationalizations for the existence of a background can be faulted in that they lead to the same problem that QED introduces, namely a sharp conflict with the 'cosmological constant' problem from General Relativity in that each envisions a horrendous quantity of energy resident at every point of space, even where absolutely free of matter.

5. TACTIC FOR A REMEDY

For the purpose of seeking an optimum paradigm for phenomena derived from the interaction of charged particles, two working principles recommend themselves: 1) all notions employed for the paradigm should be as close as possible to incontestably grounded empirical 'facts;' and, 2) continuously related (in the sense of a correspondence principle) to the successful aspects of those paradigms suggested through history. Arbitrary or not, they seem prudent and reasonable.

6. EMPIRICAL BASE

The following facts seem to constitute the essential optimum supported by observation:

1. Charges come in two genders, likes repel and un-likes attract.
2. The attraction, or repulsion, is in accord with GAUSS' Law, in other words, for static circumstances, it falls off in proportion the inverse square of the separation.
3. When a charge moves, any change in the force it exerts on other charges is delayed by a time lag linearly proportional to the separation. The proportionality constant is called the "speed of light."
4. The "speed of light" is a constant valid in all inertial frames (See caveats below).

In addition to, or preceeding the pertinent empirical facts, there are a number of more abstract or less material features that might be taken as deeply philosophical in character. The study of such aspects are often associated with KANT, but he may not have had the last word. The basic issue he addressed is: what are space and time?

What they are not is clear. Certainly they are not material objects like stones, atoms or even elementary particles; more likely they are (at least) relational categories and may be further inexplicable. Whatever else they may be, in mechanics they can be seen to be used as organizing relationships among material objects.

As a relationship, space is obviously unique. That is, there is no sense at all to the question: which space? The spatial relationships among material objects are defined strictly with respect to each other. There is no "origin" or other preferred or privileged point; it may be said that in this sense it is "absolute." All the same considerations pertain to time as an ordering parameter, except that, per simple observation, time is flowing in one direction. (As an aside, I emphasize that it is not the point here to enter into philosophical analysis of space or time. The sole point here is to take those features evident directly to observation as given *a priori*. The immediate goal is only to seek the simplest paradigm for charge particle interaction consistent with such features. The analysis of possible deviations from these first order and evident features would be a separate question, deferred to future study.)

To foreclose some misunderstandings, note that the existence of absolute time does not imply the existence of an absolute clock. Such a clock would propagate its "ticking" instantly to the whole universe, and obviously, no known material gadget could do that. Likewise there is no material "absolute meter stick," which would have to be as long as the universe is wide and have no inertia, etc. It can be argued that the non existence of these material items is what really should have been intended by the claim that absolute 'time' and 'space' do not exist. As ordering abstractions, the latter "exist" as soon as they can be defined in a logically consistent manner, just as is the case for any abstract mathematical concept. The utility of these "absolute" orderings, having been defined, for any purpose within or for a particular theory, is then an internal matter for that theory.

7. THE PARADIGM

The above suggests the following paradigm. The fundamental element is the time-directed interaction link, i.e., the notion that every charge is the source of "action" on every other charge as a sink via delayed attraction or repulsion. Each and every particle is both active (as a source) and passive (as a sink), where all particles as sinks are functions of a universal parameter conjugate to total energy (or the Hamiltonian of the universe). These links are eternal and primal; that is, they can not be further reduced to more elementary subparts; the charges at each end of a link have no independent existence.

The main difference with, and advantage over, the historical 'action-at-a-distance on the light cone' formulation, is that here there is no supposition that any*thing* is being emitted by the source and adsorbed by the sink. This has the consequence that there is no "free," un-targeted energy that eventually will be dissipated at infinity, and no energy to be thought of as "residing" at or passing through an arbitrary, but otherwise vacant point in space. Thus, the calculation of energy thought to be a source of vacuum gravitational energy is preempted from the start, thereby dispatching the 'cosmological constant conflict.'

For other paradigms, the human predilection for understanding "action" in terms of contact forces has led to the introduction of hypothetical intervening elements such as 'fields,' and 'photons,' whose function is to be, in the first instance, an agent of contact. In this way, an association is made with human experience, i.e., lifting, pushing, etc.; the only physiological means of delivering force or interaction with material objects. One might object that the concept of link leaves the essentials of interaction unexplained. But, while this is correct, it is also true of contact forces. The fact that we humans have experience with contact forces makes them intuitively predictable, but still not understandable in any deep sense, just familiar.

A pivotal issue in the historical dispute on the tenability of MAXWELL's formation of electrodynamics, is the matter of radiation reaction, or the loss of energy by a charge by cause of its accelerated motion. The classical calculations for this effect have exposed obviously defective understanding of the electric interaction, leading as they do to 'preacceleration,' or 'run-away' (divergent) solutions. This naturally evokes the question for any new proposals for a paradigm: does the new paradigm admit considerations that reasonably avoid such 'un-physical' outcomes? Elsewhere this writer has discussed this matter and shown that it appears that radiation reaction may be considered the delayed interaction of a charge with its own induced DEBYE sheath. Within this paradigm, then, the negative features of solutions to DIRAC's equation for radiation reaction can be seen to arise from approximations which neglect the delay time of the reflected signal.[8]

The dynamical aspects of a link require some elaboration. Let us imagine that a charge as source is jerked back and forth to induce a pulse in its links to other charges as sinks. By hypothesis, the pulse will travel up the link at the velocity of light. Such a pulse determines two times, t_q, the source time when the pulse is sent, and t_s, the sink time when the pulse is received. Clearly there can be absolute ambiguity at a sink between two pulses that arrive at the same (sink)-time from the same direction. Reception of pulses from the totality of sources in the universe is a physical realization of projective geometry with two complications: one, the projections are not instantaneous but delayed, and two, the projections are functions of time. For any given sink, including the eye of an experimenter, the totality of incoming pulses from all directions at a given sink-time, t_s, is the 2-dimensional surface of a sphere centered on the sink charge (or eye of an observer), sometimes called the observer's 'sky.' On this surface, overlapping pulses from sources in the same direction, but at distances such that the transmission delays compensate, can not be distinguished. This is obviously the recipe for the MINKOWSKI metric and, therefore, the justification for the MINKOWSKI space structure with the Lorentz transformations. The only difference with the usual presentation, is that from this viewpoint it is obvious that the MINKOWSKI structure pertains only to the sink times; the source times and positions are interrelated according to the Galilean transformations.

8. UNIVERSALITY OF THE SPEED OF LIGHT

Of the four points considered empirically derived and delineated above, the last, to the effect that the speed of light is the same in all inertial frames, is the weakest. To begin, it is counterintuitive; it was introduced virtually out of desperation by EINSTEIN to make Special Relativity fit together. Moreover, it requires a redefinition of the term "velocity" which was defined originally in terms of its vector character, such that as a matter of syntax, it is to be added according to Galilean transformations. This redefinition induced by EINSTEIN has never really been rationalized by lexicographers, the term has just been given a jargon meaning, distinct from the conventional meaning, solely for discussing electrodynamics and Special Relativity.

In spite of strict taboos, this difficulty re-emerges repeatedly in detailed analysis of certain phenomena. The most convincing to this writer is with respect to the SAGNAC effect (Waves sent in opposite directions around a plane figure by means of mirrors, exhibit a interference pattern dependant on the angular velocity of a platform on which the whole experiment, including sources and detectors, is mounted.). If one considers the limit of the size of the plane figure as its linear dimensions increase while the angular velocity decreases such that the tangential velocity is constant, then one has a conceptual passage from a circumstance for which there is empirical evidence of the influence of the velocity of the source, to a circumstance where, according to the fourth assumption (i.e., universally constant speed of light), the source velocity should have no influence. This conflict is symptomatic of some kind of subtle misunderstanding.[9]

Moreover, there is similar, albeit vague and vanishingly minute, evidence from time-of-flight data for radar signals to distant space vehicles. Because of the many practical effects and defects of equipment that need to be taken into account, this data is not beyond dispute, however. It is less convincing, for this writer at least, but still is a "straw in the wind."

In sum, these complications again render this paradigm, too, in need of further examination, even whilst overcoming inadequacies found in other paradigms for "light."

9. NON-LOCALITY: A BANISHED BUGABOO

One of the most alarming conclusions drawn analysis of the interpretation of Quantum Mechanics (QM), is that there should be an essential element of non-locality to the natural world. This feature is attributed not only to 'light,' but implicitly to material particles also. Its ostensible realization, however, has been confined to optical experiments, i.e., to light.

As is widely known, JOHN BELL took up this issue and deduced some inequalities for observable correlation frequencies that, he argued, had to obtain for any theory that might complete QM without reintroducing troublesome features, mostly the non-locality of instantaneous interaction. Experiments showed that these inequalities are violated, so the virtually universally accepted conclusion is: non-locality is an ineluctable fundamental characteristic of nature, specifically to include light.

However, in spite of the acceptance that this conclusion enjoys nowadays, it can be disputed. Evidently the first to identify the source of a misconception (or at least to publish a critique) was JAYNES.[4] He observed that BELL, perhaps mislead by bad notation, misapplied the chain rule for conditional probabilities and, instead of encoding locality into his formula, inadvertently encoded simply statistical independence.

The derivation of a BELL Inequality starts from BELL's fundamental *Ansatz*:

$$P(a,b) = \int d\lambda \rho(\lambda) A(a,\lambda) B(b,\lambda), \tag{1}$$

where, per *explicit assumption: A*, a measurement result from one side of a correlated photon pair as envisioned by EINSTEIN, PODOLSKY and ROSEN, is not a function of *b*; nor *B* of *a*; and each represents the appearance of a photoelectron in its wing, and *a* and *b* are the corresponding polarizer filter settings. This is motivated on the grounds that a measurement at station *A*, if it respects 'locality', so argues BELL, can not depend on remote conditions, such as the settings of a remote polarizer.

JAYNES' criticism is that Eq. (1) results from a misconstrual of BAYES' formula, or the 'chain rule' for conditional probabilities, namely:

$$\rho(a,b,\lambda) = \rho(a|\,b,\lambda)\rho(b|\,\lambda)\rho(\lambda), \tag{2}$$

where $\rho(a,b,\lambda)$ is a joint probability distribution and $\rho(b|\,\lambda)$ is a *conditional* probability distribution. JAYNES points out that BELL takes it that the presence of the variable *b* in the factor $\rho(a|\,b,\lambda)$ implies instantaneous action-at-a-distance. This is true, however, only for the quantum case for which it is understood according to VON NEUMANN's measurement theory that wave functions are superpositions of the possible outcomes (even when mutually exclusive) whose ambiguity is resolved by collapse precipitated by the act of measurement. Eq. (2), however, for application in non-quantum circumstances implies no more than that there was a *common cause* for a *coincidence* in the past light cones of both measuring stations, a precondition which in QM is preempted by superposition.

The upshot is, that the inequalities that BELL and disciples derived, are valid only for statistically independent events, contrary to the fundamental assumption of the EPR argument, that the systems be correlated. Naturally, then, experimental results have little connection to the widely believed conclusions. (Arguments coming to the same conclusion as BELL's, but not involving inequalities, are also invalidated by error; in this case, not in mathematics, but in, as BARUT observed first, the simultaneous application of formula to events that physically cannot be coeval.[10])

JAYNES' point has been rediscovered by various researchers in various styles and considerably extended. This writer, for example, has presented calculations using the *classical* formula for higher order correlation to accurately calculate the intensity curves seen in both EPR (2-fold) and GREENBERGER, HORNE and ZEILINGER (GHZ) or (4-fold) correlations. In addition, he has presented a data-point-by-data-point simulation of EPR experiments showing in detail just how the intensity variation as a function of angle arises without non-local interaction being involved in any way. The conclusion from this work is: there is no need whatsoever for quantum concepts to fully explain EPR and GHZ correlations; and, in particular, there is no evidence from any of these experiments for the existence of non-locality (or teleportation) in nature.[11]

10. CONCLUSIONS

Photons, it can be said beyond doubt, present a challenge for contemporary physics. They exhibit two features that call for reconciliation with empirical facts: one, they are an essential element of QED, the paradigm-package which is in drastic conflict with General Relativity; and, two, the issue of their physical extent and interplay with other photons wherever interference comes into play, is not just unclear but contradictory. Nevertheless, as a paradigm, the notion of photon has been fruitful to an astounding degree, so that it can be expected that an improved paradigm will somehow encompass their historical contribution to understanding interaction between charged particles.

One other thing that is beyond doubt is that the classical wave paradigm presents equal challenges. Most of the inadequacies of MAXWELL field theory have been known virtually from the start. Many were never attacked thoroughly, as historically the development of QM stole the show leaving research in 'classical' E&M as a disparaged step child. But again, the wave paradigm has been, and continues to be, so fruitful that we can be certain that the truth it contains will be retained in an improved story, most probably as the intuitive imagery associated with FOURIER analysis of expressions for the full but unwieldy total interaction.

In any case, this writer holds, the optimum tactic to improve the paradigm for 'light' is to hew as close as possible to directly experienced, empirical data, without introducing hypothetical constructions. Historically, it has been these hypothetical constructions that eventually led to both contradictions and constraints on imagination impeding progress. Such hypothetical notions in the course of time take on in the folklore a sense of 'reality' altogether undeserved but vivid,

so that eventually it becomes the implicit goal of science to explain these constructions, in place of nature herself. 'Fields' and 'photons' are prime examples; both have lead to the idea, now very widely spread, that radiation can detach from its source and exist independently, as if it were a kind of ethereal matter. This is nowhere supported by evidence, however, and is responsible for what can be called "the biggest problem" in physics—that is, the disparity between the minimal ground state energy in the presumed free electromagnetic radiation fields as called for by QED, and the maximum energy level allowed by General Relativity. Taking all acceptable cut-offs into account, puts this at a minimum of 120 orders of magnitude!

The basic facts of the electric interaction seem to point to a permanent, time-directed link between charges, with one serving as, so to speak, a source and the other as a sink; with the complication that each also is linked in the complimentary sense, and then with every other charge in the universe. Impugning more to electric interaction than these bare essentials risks introducing again misleading constructions and irresolvable misconstuals.

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