Resolution of the Wave-Particle Paradox of Light using a New Approach, Part II: Computer Modeling for the Double-Slit Interference Pattern*

A. R. Jadhav† and S. R. Kajale
Pune Institute of Engineering and Technology (Formerly, COEP), University of Pune, India
(Dated: 14–17 December 2005)

This is the Part II of a two-part series of papers. Here, first, the findings of the quantum double-slit experiment are briefly explained on the basis of the new approach. The results of a preliminary computer simulation are presented in juxtaposition with the available experimental results [1]. For comparing and validating quantum theories, a new experimental test is being suggested. The proposed test actually is a very simple and practically possible modification to the quantum double-slit experiment. The test is designed to verify a new prediction that directly arises out of the new approach. To the best of our knowledge, such predictions can logically be made only on the basis of the new approach and no other previous theory.

I. EMISSION, ABSORPTION AND PROPAGATION OF QUANTA

Light quanta are emitted at the source.

The concept of quantum refers to a certain kind of spatially discrete pattern which occurs within the luminiferous aether. Examining the nature of such a localized pattern in relation to the spatially confined waves is out of the scope of this paper.

However, it may be sufficient to note that in the present view, quantum can be defined without recourse to group waves. Indeed, at any instant, a quantum may be imagined to be extended not beyond the distance of one wavelength, without much loss of generality.

In common with waves, quanta are patterns, thereby representing transport of momentum and energy, not material. In common with material particles, they can be identified with definite regions of space. Thus, in the context of the appropriate limiting process, both wave and point-particle are valid idealizations of light quanta.

A straight line-trajectory of a material particle (e.g. a grain of sand), however, is an invalid idealization for its path, just as the continuum form of the Huygens' process is an invalid idealization for its propagation.

Absorption is considered here as a probabilistic process because the deterministic law governing the interaction of the quantum with the absorber is not known fully well. However, one quantitatively crucial feature of the physics governed by this unknown law *is* well known, namely, that the absorption probability is directly proportional to the intensity of the electromagnetic field that a quantum represents. (The intensity is obtained by multiplying the value of the complex wave function at the absorber point with its conjugate.) This in turn implies that the "random" fluctuations within both absorbers and emitters respond linearly to energy changes in quantum exchanges. Thus, though not fully understood and therefore probabilistic as of today, the physical mechanism is known to be simple; it obeys linear mathematics.

From emitter to absorber, quanta follow the finitely-sampled Huygens' process, tracing a spatially definite path.

The path in space traced by *a single quantum* is deterministic—else a buildup to a precisely continuum wave-like interference pattern would not result.

It is true that as of today, in the present theory, the path for any pre-selected photon cannot be predicted (along with precise times for emission or absorption). But the present theoretical framework is sufficiently general to be able to accommodate any future law that may predict the local fluctuations. Such a law would remove even the non-essential randomness from the present theory, by indicating how the finite sampling is to be carried out for each Huygens' wavelet. Until that time, for computational purposes, pseudo-random generators [2] may be used in the place of the law. (It seems that a discovery of an analogous law governing the motion of molecules in atmosphere and oceans would occur first. Yet, in principle, an imagined difficulty in the way of discovering an anticipated natural law cannot be used as an argument to summarily eject the very possibility of that law out of theory.)

II. EXPLANATION OF THE DOUBLE-SLIT EXPERIMENT, AND COMPUTER SIMULATION

In the present approach, the path of *a single quantum* from a slit to the screen forms a definite and continuous curve. Such a curve, for most quanta (though not all) would not be differentiable at every point. As the simplest view, also in harmony with the available experimental evidence, the continuous path goes through only one slit at a time; the path (or the quantum) does not split up. (However, rarely, the same path may loop from one slit to another, perhaps many times over.)

For a shower of quanta, due to the *uniformity* of the finite sampling in particular, and the nature of Huygens' process in general (covered in Part I), the interference pattern ultimately does build up at the screen.

In contrast to the waves-based interpretations, the new approach does not require any special collapsing (or coalescing) mechanism at the absorber (or the emitter), or any hidden variables. (Huygens' wavelets cannot be regarded as hidden variables in quantum phenomena for precisely the same reason that infinitesimals cannot be taken as *hidden* in Newton's gravitation theory.)

See Figures 1 and 2. The simulation results display remarkable visual similarity to the experimental evidence. Yet, we hasten to add that a few qualifications are in order about these preliminary simulations. The simulations were actually conducted only with a planar version

*Published in the *e-Proceedings of the 50th Congress of the Indian Society of Theoretical and Applied Mechanics (An International Meet)* held at IIT Kharagpur, during December 14–17, 2005, paper no. MCO4. *Ed.* B. Pradhan, *Pub.* ISTAM, IIT Kharagpur, India
†Electronic address: ToneBrush@vsnl.net

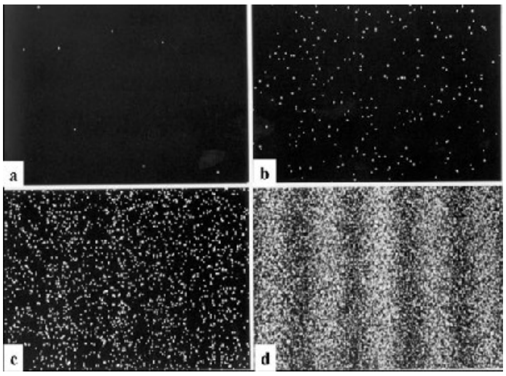

FIG. 1: Experimental results of the double-slit interference buildup of electrons (Image downloaded from the Internet [1]). This experiment was conducted with electrons, not photons. The number of electrons are reported in [1] as (a) 8, (b) 270, (c) 3000, and (d) 6000. For figure (d), the number is likely to be 60000 electrons, not 6000. A reproduction in [3] of a comparable figure, citing the same original source, does state the number as 70000.

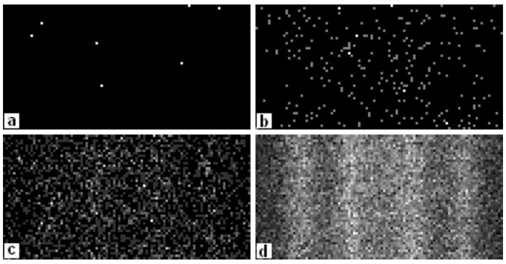

FIG. 2: Computer-simulation of the photon build-up pattern, using the new approach. The number of photons are: (a) 10, (b) 300, (c) 3000, and (d) 60000. The lateral portions of the figures have been cut off to afford a better visual comparison with the experimental results. However, the remarkable visual similarity does not imply that important considerations such as the effective slit-width, uniformity of field, absorption boundary conditions and angle of diffraction, distance before the screen, etc. also are strictly comparable. Even more importantly, all the simulations are for a planar chamber (i.e. not even a properly 2D situation). Refer to the main text of this paper for the necessary qualifications to be applied.

of the interference chamber, and the interference results at the screen (actually existing in the form of a line in the planar-chamber) were then vertically distributed to give a rectangular screen appearance. No grave harm results out of this procedure because there is symmetry in the field distribution around the horizontal mid-plane in a 3D chamber. Of course, a planar interference chamber cannot give highly accurate results for amplitudes of cylindrical waves—the properly 2D situation. Yet, across the horizontal direction, i.e. the only direction in which the fringes can at all be distinguished for a long and slender slit, the interference pattern so obtained is expected to remain fairly similar to a 3D trial (out of symmetry considerations). Thus, certain interesting mathematical issues concerning the 2D- versus the 3D-process are acknowledged lacking here; these mathematical issues imply further work in simulation also to make the model realistic.

In the present view, the reason that a quantum detector placed near a slit collapses the *interference* pattern is because most quanta coming in the near vicinity of the detector are terminally absorbed by it. Note that a real detector cannot be a fully passive device; for its operation, it must expend finite amount of power, no

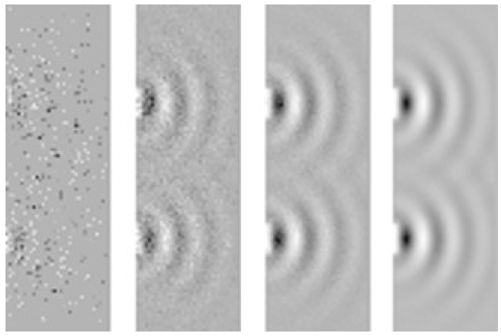

FIG. 3: Computer simulation of the build-up of wave pattern. This is a plan view showing four stages of a planar simulation. The number of particles here are 100, 300, 3000, and 60000, respectively. The transition from the particle to the wave description is clearly seen. All the four sides of the chamber (including the screen) are terminally absorbent. The slits are 10 units wide, and their centers placed at a distance of 45 units. The wavelength of the simulated light is 10 units. Notice that while the screen distribution pattern (shown above in Figure 2) takes a somewhat longer time to refine, the overall or global field pattern does appear quite early in the simulation. This fact makes the present approach an attractive computational method even for mechanics of continua, even more so for automated optimization in engineering design.

matter how small. Consequently, when switched on, it must have a spatially extended field of its own *receptive* influence (i.e. taken not as a negative field, but as the modification it brings about to the chamber field while being switched on). A quantum caught in such a local field of the detector would be likely absorbed by it. The contribution to the overall distribution at the screen that would have come from the quanta that happen to wander near the detector (i.e. the slit) is thus eliminated through the terminal absorption at the detector. For the buildup pattern, the result is indistinguishable from materially closing the slit.

Hence, with the detector turned on, only the pattern appropriate to a single slit emerges. (Though not shown here, this circumstance has been verified in computer simulation wherein even as many as 10% photons escaping the switched-on detector still do not produce an immediately recognizable double-slit pattern at the screen, especially at the early stages of the quantum buildup.)

The experimental fact of the switched-on detector at least partly collapsing the double-slit pattern helps support the conclusion that photon passes through only one slit at a time—i.e. paths in the finitely-sampled Huygens' Process do not split up.

III. SUGGESTIONS FOR NEW EXPERIMENTAL TESTS

In the double-slit experiment of light, it is suggested to add an extra photo detector on one of the *lateral* sides of the interference chamber, see Figure 4.

The idea is to have a detector closer to the slits than to the screen. Being at a large distance from the screen, the extra detector will not much alter the distribution that builds up at the screen. Now, as the crucial element, take *time-series* recordings of each quantum that hits each detector (or each pixel of the CCD camera).

A prediction logically possible with the present theory is that *some* photons will hit the more distant screen *earlier in time* than the extra detector placed closer to

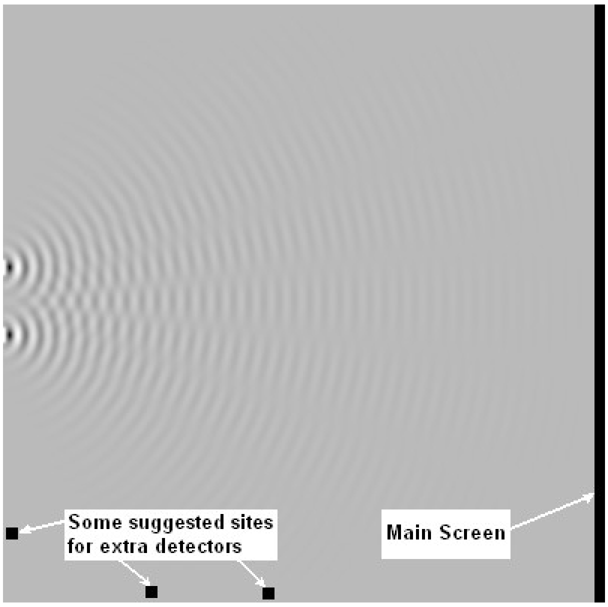

FIG. 4: New experimental test being proposed for the single-quantum double-slit interference buildup experiments.

This figure brings out how the test proposed in this paper actually is an extremely simple and practically possible variation on the experiments already performed [1, 4, 5]. A few possible sites to place the extra detectors at are shown in the figure. The new approach permits statistical time-series predictions to be made.

This figure clearly shows how the boundary conditions at the walls, including those imposed at the screen, do affect the diffracted field within the chamber. For example, note that no appreciable fringes are seen near the opaque wall containing the slits. Incidentally, this figure also brings out the effectiveness of the new approach for large-flux simulations. Note the regular, fine details obtained for the wave-field, making one almost forget the fact that a random number generator [2] was used in producing it. This simulation involved 106 (one million) particles. The time taken on a single personal computer (Intel Pentium IV running at 3 GHz clock-speed, with Microsoft Windows 2000 Professional operating system) was less than an hour, even without effecting any form of code optimization whatsoever.

the slits would.

Though this prediction *seems* very obvious, logically speaking, such statements cannot at all be made proceeding only from the theoretical bases of the other quantum theories. What is common to all quantum theories is that the large-flux distribution each predicts remains identical—but not their single-quantum buildup. The theories from the standard model (i.e. those based on probability-waves) cannot make such predictions, because they are built after removing all temporal order at every scale: *local* and global [6]. On the other hand, in the wave description-based theories, including those with hidden variables, the time before the first hit at the extra-detector will necessarily be an invariant for a given experimental set up, i.e. it will not be a statistical distribution. Unfortunately, both kinds of implications have never been put to test before.

In contrast, the new approach retains complete temporal order at the local scale, and then even globally for a single photon. (This is exactly similar to the fact that the motions of the individual molecules are not denied temporal order in the kinetic theory of gases.) However, on a global scale, because the appropriate law is not yet discovered, the new approach can only statistically predict the time elapsed before the first quantum absorption occurs at a specified point. Yet, despite thus having a statistical nature, unlike the standard model, the new approach does permit a time-series based prediction to be made, thereby opening an entirely new class of predictions.

Further proposals for experimental tests will be published in due course of time. Experimental evidence coming from the proposed tests will ultimately determine how the two kinds of earlier theories, and the present theory, measure up against reality—the final arbiter.

IV. CONCLUSIONS (FOR PARTS I AND II)

A new view of quantum propagation of light has been presented and the wave-particle paradox of light resolved. Aether is shown as necessary in physics theory, on the basis of the specifically physical considerations. The aether gets disturbed by light source in such a way that a spatially discrete pattern of disturbance within the aether, viz. photon, results. Therefore, the finitely-sampled Huygens wavelet is the natural unit for the propagation process. The local conditions existing instantaneously at a point affect and alter the spatial progress of the quantum. The changes in the directions of propagation that a quantum suffers are controlled by a deterministic physical law that is not yet discovered. Therefore, for computational purposes, randomness is introduced in the finitely-sampled Huygens process. It is shown that such randomness is not a fundamental feature of the physical process and doesn't make quantum phenomena subjective or un-deterministic. While the said physical law is not yet known, one crucial quantitative feature of the law is: viz., that it gives rise to long-run isotropy for quantum propagation, taken in both senses—for a single quantum along its path, and at a fixed point of space over time. In common with material particles, each quantum traces a continuous line path that passes through only one slit at a time. The framework of the new approach is general enough to accommodate a differential form of law in place of Planck's energy discretization hypothesis. However, spatial discreteness of light propagation is considered inevitable owing to the evident collapse of the quantum interference pattern when a detector near a slit is switched-on. Most essentials of the new approach have been given, but several issues, noted in the paper, are out of the scope.

Computer simulation following the new approach shows a remarkable similarity to the experimental evidence, and suggests a new class of experimental tests which should be undertaken towards validating and differentiating all quantum mechanical theories—previous theories and the present one. The suggested tests are very simple, even undemanding sort of variations on the experimental arrangements that have already been reported and replicated.

To the best of our knowledge, the new approach, formulated in this research program, was the first to explicitly accommodate a probabilistic (particularly, stochastic) view of wave fields starting from Huygens' Principle; and to precisely indicate the nature of its relation to the corresponding continuum view [7].

This research program now is the first to resolve the wave-particle paradox, by addressing the gradual buildup in the double-slit interference pattern.

It is satisfying to note that theoretically and computationally, the same approach to wave-fields remains applicable for modeling the continuum phenomena of engineering interest such as: engine silencers; modeling of steady-state and transient heat conduction; radiation form-factor calculations; vibration analysis; acoustics of concert halls; microwave and antenna engineering; lasers and optical engineering, geotechnical engineering; and many other subjects from every branch of engineering and physics. When taken as an engineering computational method, even if the initial results of the new approach are highly encouraging, computational complexity is yet to be looked into.

---

[1] Tonomura et al (2005) "Double-slit experiment;" Web document copyright of Hitachi, Ltd., available at `http://www.hqrd.hitachi.co.jp/em/doubleslit.cfm`, accessed on September 21, 2005

[2] Press W. H., Teukolsky S. A., Vetterling W. T. and Flannery B. P. (2002) *Numerical Recipes in C++: The Art of Scientific Computing*, Cambridge UP

[3] Halliday, Resnick and Walker (2001) *Fundamentals of Physics*, John Wiley flow on computer," *Proc. 48th Cong. ISTAM*, *pub.* IIT Kharagpur, pp. 142–150

[4] Rodgers P. (2002) "The double-slit experiment;" editorial of *Physics World*, Sept. 2002, available at `http://physicsweb.org/article/world/15/9/2`, accessed on September 21, 2005

[5] Afshar S. S. (2003) "Sharp complementary wave and particle behaviours in the same welcher weg experiment;" e-preprint at `http://www.irims.org/quant-ph/030503`, accessed on 26 September 2005

[6] Feynman R. P. et al (1963) *The Feynman Lectures on Physics, 3 Vols.*, Narosa

[7] Jadhav A. R. and Chikate P. P. (2003) "A new numerical approach for modeling the ideal fluid flow on computer," *Proc. 48th Cong. ISTAM*, *pub.* IIT Kharagpur, pp. 142–150