Interpretation of a Recent Experiment on Interference of Photon Beams

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The interpretation of an important recent experiment by Pfleegor and Mandel according to the causal formulation of the wave-particle dualism is developed. This interpretation is simpler and seems more satisfactory than that provided by the current ideas on the nature of light.

A FINE recent experiment by Pfleegor and Mandel[1] has shown that it is possible to detect the existence of interference fringes due to the superposition of waves emitted by two independent lasers under such conditions that there are practically never two photons arriving at the same time in the interference apparatus. The interpretation of this result by means of ideas accepted at present in quantum physics is difficult, as may be seen by reading the conclusion of the article by Pfleegor and Mandel. In contrast, it seems to us to be very simple and very clear if based on the ideas that one of us (L. de B.) has adopted for some years on the nature of the coexistence of waves and particles. We are going to demonstrate this, but, since our ideas on the subject are little known, we shall start by giving a very brief outline of them. For further information one may refer to the publications indicated in Ref. 2.

For us, according to classical concepts, a particle is a very small object which is constantly localized in space, and a wave is a physical process which is propagated in space in the course of time according to a given equation of propagation. This wave, which we call the wave v, must be clearly distinguished from the statistical wave ψ, which is arbitrarily normalized in current quantum mechanics, and which is linked to it in a manner described in our former publications. This wave v has a very low amplitude and does not carry energy, at least not in a noticeable manner. The particle is a very small zone of highly concentrated energy incorporated in the wave, in which it constitutes a sort of generally mobile singularity. By reason of this incorporation of the particle in the wave, the particle possesses an internal vibration which, as it moves, remains constantly in phase with the vibration of its wave. In our former papers, we have shown that the "mean" path of the particle is determined according to the shape of the wave by a certain "guidance law," but this motion has superposed on it continual fluctuations corresponding to a hidden thermodynamic behavior of the particles.[3] From this can be deduced the probability expression for the particle's being in the volume element $d\tau$ of space at the instant t. If the Schrödinger equation can be used for the wave v, the expression has the well-known form $|\psi|^2 d\tau$.

If the preceding general ideas are applied to the special case of electromagnetic waves and photons,[4] one is led to consider the wave v of the photons as a very weak electromagnetic wave obeying the Maxwell equations very closely. It is this circumstance which explains, we think, the fact, which at first seems paradoxical, that Maxwell's electromagnetic theory suffices to interpret a very large number of phenomena although it does not acknowledge the existence, however certain, of photons. Actually, according to the guidance law, the distribution of photons in space and the phase of their internal vibrations happen to agree completely with the predictions of the electromagnetic theory. In an interference field, the probability of a photon's being present at a given point is, therefore, proportional to the square of the amplitude (intensity) of the wave v at that point, in such a way that the statistical distribution in the interference zone of a large number of photons is the one provided by the electromagnetic wave theory.

We shall now expound our interpretation of the result of the Pfleegor-Mandel experiment by using the concepts that have been summarized. We think that in the cavity of a laser a stationary electromagnetic wave v is formed, into which photons are emitted by certain atoms in a stimulated-emission quantum process. Part of the wall of the cavity is slightly semitransparent. The inside wave v therefore filters slightly to the outside for the entire duration of the laser emission. In the case of two independent lasers arranged in such a manner that the waves v that they emit come to be superimposed in an interference apparatus—as is the case in the experiment in question—*there exist interference fringes in the apparatus even if there is no photon that permits one to detect them.* It is, moreover, physically evident that each photon arriving in the interference zone comes from that laser where the atom was that emitted it by a stimulated transition.

[1] R. L. Pfleegor and L. Mandel, Phys. Rev. **159**, 1084 (1967).

[2] Louis de Broglie, *Non-Linear Wave Mechanics: A Causal Interpretation* (Elsevier Publishing Company, Amsterdam, 1960); *The Current Interpretation of Wave Mechanics: A Critical Study* (Elsevier Publishing Company, Amsterdam, 1964); *Certitudes et incertitudes de la Science* (Albin Michel, Paris, 1966).

[3] Louis de Broglie, *La Thermodynamique de la particule isolée (ou Thermodynamique cachée des particules)* (Gauthier-Villars, Paris, 1964); Ann. Inst. Henri Poincaré **1**, 1 (1964).

[4] Louis de Broglie, Energie Nucléaire **7**, 135 (1965); *Ondes électromagnétiques et Photons* (Gauthier-Villars, Paris, to be published).

If the lasers emit very few photons to the outside, a photon will emerge, from time to time, from one of the lasers and arrive on its own in the interference field. If it manifests its presence by being in an observable location, this will be mostly in a high-amplitude zone *of the superimposed waves v emitted by the two lasers*. The movements of the photon in the interference zone are actually guided by that superposition, and not by the single wave that carried it to the exit of the laser where it was born.

If after a sufficiently long time (on the scale of the very short duration of a laser impulse) a sufficient number of photons arrives in the interference zone, coming from one or the other laser, so that the interference fringes can be detected, these photons will be statistically distributed in that zone in proportion to the local intensities of the electromagnetic waves v. Although the photons arrive singly one after another, one can in the end observe the interference fringes for exactly the same reason that they can be observed in ordinary very-low-intensity experiments of the Taylor type. The interpretation of the experimental result of Pfleegor and Mandel thus obtained seems to us to be very clear and very satisfactory.

However, we should like to emphasize certain important points of our interpretation.

A photon coming from one laser or the other and arriving in the interference zone is guided—and this seems to us to be physically certain—by the superposition of the waves emitted by the two lasers, and it is for this reason that it is impossible to know in which of the two lasers it was born. Our interpretation of this impossibility does not involve either the Heisenberg uncertainty relations or the undiscernibility of bosons, which in our opinion is only apparent owing to random disturbances undergone by the photons, and does not imply a loss of identity.

The error committed today when trying to give an interpretation of this kind of phenomenon is, we believe, to speak of interferences between photons as if the interferences were due to the photons. It has actually been known since Fresnel that interferences are a phenomenon of wave origin. The interferences of an electromagnetic wave v are produced, in our opinion, in the classical fashion, but because of the very low intensity they cannot be observed by themselves. However, because of the guidance of the photons by the superposition of the waves that interfere, the arrival of a photon at a point of the interference zone will be all the more probable as the amplitude of the wave v resulting in that point increases. It is, therefore, in the zones of highest intensity of the wave that the photons will have the greatest chance of producing observable local phenomena, such as a photoelectric effect, local blackening of a photographic plate, etc. In short, it is not the photons but the electromagnetic waves v that produce the interferences; the part played by the photons, which is important, is only to permit one to detect the interferences by the manner in which they are statistically distributed in the zone where these interferences exist.