Quantum optics experiment on the test of empty wave hypothesis

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Abstract

The experiment measured the absorption of single photons by absorbers with various absorption coefficients, in one of the beams, after the photons interacted with the beam splitter. The measurements showed that the absorption corresponds to single photon traveling in either one or another beam. The measurements support the original empty wave hypothesis which has been advanced in a number of works.

Key words: single photon experiment, subquantum processes, empty wave, Broglie-Bohm theory

Introduction

In 1986 Grangier, Roger and Aspect [1] have demonstrated the interference of the two output beams from the beam splitter in experiments using single photon states, even though the photon can only be detected in one of the two output beams for a given run of the experiment. Paper [2] considers the hypothesis that one of the beams contains a wave which is not accompanied by a particle, i.e. an empty wave. A number of works suggest experiments for the detection of empty waves (see, e.g. [3-5]); however, until now no experimental evidence of the existence of such a wave has been received.

The Born rule connects the wave function to the probability density of finding the particle at a given point. However, this rule is not a basic law. In Broglie-Bohm theory the wave is considered a physical reality, and the link between the probability density and the wave function has the status of a hypothesis. This means that the wave function may be not equal to zero even in the part of space where the particle is not observed. Hence, an empty wave may also be described by the wave function, which may explain the interference of the wave containing the photon, i.e. the probability wave or full wave, and the empty wave. In paper [2] some assumptions are made which are true in the de Broglie-Bohm model.

Clearly, in order to discuss the empty wave hypothesis it is important to understand the physical meaning of the wave function, i.e. to have an adequate interpretation of the wave function. We will not discuss various interpretations of wave function here. The fact that so many exist testifies to the absence of a satisfactory one. This is why many physicists lean towards the instrumentalist interpretation, best summed up in the succinct slogan "Shut up and calculate!" [6].

Like many physicists, we are uncomfortable with any of the commonly known interpretations. In our view, for a particle to be found in a point in space, it must actually be there at the moment when it is found. It is clear that for a particle to be manifested at a point in space, physical processes are needed to provide for this manifestation. In the early 1960ies, de Broglie formulated an approach adding a chance element to the movement of a particle; this chance element is caused by the particle's interaction with the hidden "subquantum environment". In papers [7,8] we offer an interpretation of the wave function in which wave function is a consequence of processes taking place at the level of the organization of matter which underlies the phenomena described by quantum mechanics. We use the term "subquantum processes" for these processes. We think that the road into the structure of matter is a staircase with an infinite number of steps, and the subquantum level is one of these steps.

Experiments observe the manifestation of the particle in a certain point of the probability wave. It is common knowledge that behind every chance there is a rule. We do not know the rules of the subquantum world determining the formation of wave trains in which the particle manifests as an observable object. It is clear, however, that the photon can manifest anywhere in the wave train, and that this possibility is determined by some subquantum processes. A direct proof of the existence of an empty wave would mean that along with the wave train where the photon manifests, there also exists a wave train containing the potential possibility of the photon manifestation, but the actual photon does not manifest, and thus cannot be detected. Note that at any given time the photon manifests only in one of the points of the probability wave train. In all other points at that moment the wave may be considered empty.

According to [1], after the recombination of two beams an interference picture is observed. This implies that two coherent wave trains appear as a result of the interaction of the photon with the beam splitter. If the photon were to manifest in both wave trains, it would mean that its wave function is the superposition of two probability waves: the transmitted one and the reflected one. Note, that the photon can only be detected in one of the two output beams. The empty wave hypothesis is consistent with the suggestion that the photon manifests in only one of the two output beams. In this case the photon's wave function cannot be a superposition of two probability waves. Thus, experiments are needed which will clarify whether the photon wave function after the interaction with the beam splitter is the superposition of two probability waves, or the superposition of a probability wave and an empty wave.

Experiment and discussion

Our experiment is illustrated in figure 1.

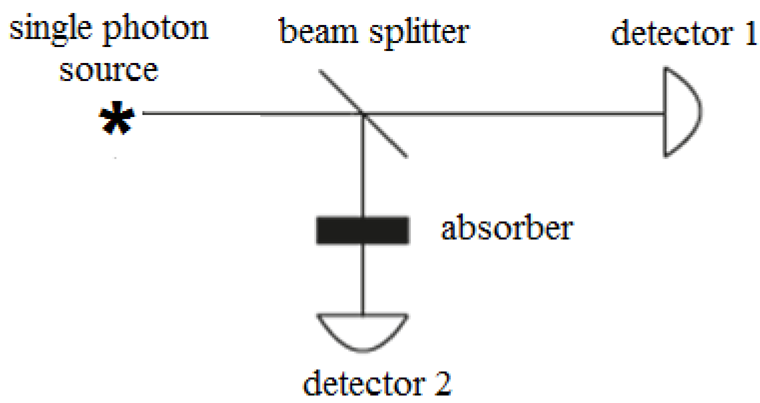

Fig.1

The measurement results are provided in Table 1.

k	T	N_1	N_2	N_1/N_2	$(N_1/N_2)_{av}$
0	2	44730	33745	1.325	
0	0.02	459	343	1.339	1.346
0	0.002	45	33	1.373	
0.1	2	44271	26068	1.698	
0.1	0.02	433	255	1.696	1.701
0.1	0.002	43	25	1.710	
0.2	2	44188	20502	2.155	
0.2	0.02	446	2106	2.118	2.096
0.2	0.002	44	28	2.016	

Table 1. Column names:

k - absorption coefficient of the absorber

$T = 20\ T_m$

T_m - duration of one measurement cycle

N_1 - average number of photons registered by detector 1 in one measurement cycle

N_2 - average number of photons registered by detector 2 in one measurement cycle

$(N_1/N_2)_{av}$ - average ratio of the number of photons registered by detector 1 and detector 2 at different T

The table 1 shows that the average ratio of transmitted photons and photons which were reflected without an absorber is 1.346 (with variation in the third decimal at various values of T).

If the photon's wave function after the interaction with the beam splitter were a superposition of the probability waves, then the presence of an absorber would reduce the number of unabsorbed photons recorded by both detectors. In our case, the probability of the photon manifesting in the probability wave which is passing through the absorber, is 42.73%. Accordingly, the probability of the photon being absorbed should go down, but the ratio of the unabsorbed photons recorded by detectors 1 and 2 should remain 1.346.

In the presence of the absorber in the path of the reflected beam, the number of unabsorbed photons recorded by detector 2 corresponds up to the third decimal to the expression

$$N_2 = (N_2)_0 10^{-k} \tag{1}$$

where $(N_2)_0$ is the number of photons recorded by the detector 2 in the absence of the absorber. We see that the probability of the photon being absorbed does not change.

The presence of the absorber did not change the number of photons recorded by detector 1. In the presence of the absorbers the ratio between photons registered by detectors 1 and 2, also corresponds up to the third decimal to the expression

$$\frac{N_1}{(N_2)_0 10^{-k}} = 1.34598 * 10^k \tag{2}$$

Expressions (1) and (2) correspond to the photon traveling in either one or another beam. This means that the photon's wave function after the interaction with the beam splitter is not a superposition of two probability waves. However, for the interference in experiments [1] to be observed, two waves must be superposed. This means that while the photon is traveling through one beam, an empty wave is traveling through the other beam. In other words, the wave function of the photon after the interaction with the beam splitter is the superposition of a probability wave (full wave) and an empty wave.

In the presence of the absorber we observe the interference between the probability wave of the unabsorbed photon and of the empty wave, just as experiments in [1] observed in the absence of the absorber.

Conclusion

The results of our measurements and of experiment [1], combined together, demonstrated the existence of an empty wave. Quantum mechanics is a fundamental theory which allows to describe a vast number of physical phenomena. However, as a truly fundamental theory, it cannot explain and describe itself. Accordingly, quantum mechanics says nothing about subquantum processes which provide for the existence of an empty wave.

The survey "Models of wave-function collapse, underlying theories, and experimental tests" [9] points out: "Quantum mechanics is an extremely successful theory… One should of course stay cautioned against assuming that quantum theory will be successful through and through … The fact that a theory is extremely successful in one part of the parameter space should not be taken as a guarantee that it will continue to be successful in a different part of the parameter space … And there are historical examples of long-standing successful theories eventually turning into approximations to more general theories when their extrapolation into a new part of the parameter space failed to be confirmed by experiment."

Experimental proof of the existence of an empty wave may be useful in developing a more general theory, to which quantum mechanics will be an approximation.

References

[1] P. Grangier, G. Roger and A. Aspect, Europhys. Lett. 1 (1986) 173.

[2] L. Hardy, "On the existence of empty waves in quantum theory", Physics Letters A, 167, issue 1, page 11 (1992).

[3] J. R. Croca, "An experiment for detection of empty waves", Physics Letters A, 124, no. 1,2, page 22, (1987)

[4] Peter E. Gordon, "Can empty waves be detected?", Physics Letters A, 138, no. 8, page 359, (1989)

[5] Sofia Wechsler, About empty waves, their effect, and the quantum theory, arXiv:1008.4849v1 [quant-ph]

[6] Mermin, D.: Could Feynman Have Said This? Physics Today **57** (5) 10-11 (2004)

[7] V.A. Skrebnev, M.V. Polski, Some issues of quantum theory and subquantum processes, arXiv:1701.03019v4

[8] Polski, M.V., Skrebnev, V.A., An alternative derivation of canonical distribution as a result of irreversible processes in macrosystems, Eur. J. Phys. 38, 025101 (2017)

[9] A. Bassi, et all, Models of wave-function collapse, underlying theories, and experimental tests, Reviews of Modern Physics, 85, 471 (2013).