Experimental Results of Aspect *et al.* Confirm Classical Local Causality

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Abstract

The claims of Aspect, Grangier, and Roger of having obtained experimental results that violate Bell's inequality, confirm traditional quantum theory, and disagree with classical local causality are shown to be incorrect. They incorrectly discard events, which they call "accidental." When these events are correctly retained, their results confirm classical local causality by agreeing with classical physical optics and thus with Wesley's causal quantum theory as well.

Key words: traditional quantum theory, local causality

1. BACKGROUND THEORY

The Einstein-Podolsky-Rosen[1] (EPR) paradox shows that if expectation values that involve an integration over all space are used as observables, then an observation at one point in space can cause an instantaneous correlated observation at a distant point without any physical connection between the two points being required. EPR concluded that traditional quantum theory that involves such expectation values as observables is incorrect or "incomplete." Bell,[2] questioning the conclusion of EPR, proposed an inequality that is satisfied if local causality is true but is violated if traditional quantum theory is correct.

Aspect, Grangier, and Roger[3-5] claim to have experimentally demonstrated an effect produced by a distant cause without any possible physical connection being involved. The observation of the polarization of light at one point in space is supposed to cause a particular polarization to be observed at a separate point in space without any physical connection being involved. They claim (1) to have demonstrated the violation of Bell's inequality, (2) to have confirmed traditional quantum theory with its expectation values as observables, and (3) to have shown the failure of ordinary local classical causality. Much literature[6-9] has accumulated trying to explain these most remarkable claims.

The ordinary classical physical optics prediction for the experiment of Aspect *et al.* is derived here first. The research of Aspect *et al.* is then examined to see if they have discarded unfavorable data in order to establish their claims. This is indeed found to be the case. Although all the coincident counts that Aspect *et al.* observe between their widely separated photomultipliers are necessarily relevant and significant, they discard a sizable fraction of these coincidences as being "accidental" in order to establish their claims. When all their data are properly included, the classical physical optics prediction is obtained, local causality is confirmed, and the traditional quantum theory prediction is not confirmed.

It may also be noted that the results of Aspect *et al.*, when all coincidences are properly retained, agreeing with classical physical optics, necessarily agrees with Wesley's[10-13] causal quantum theory as well. Wesley's causal quantum theory prescribes quantum particle velocity as $\mathbf{w} = \mathbf{P}/E$, where $\mathbf{P}$ is the classical Poynting vector and E the classical wave energy density. Observables are then obtained by the appropriate operations on $\mathbf{w}$ as a function of position and time. Wesley's theory, being based upon classical wave theory, is compatible with all classical wave theoretical results. It also yields the observed results for bound systems, such as described by Schrödinger's time-independent equation. Since observables are not taken as integral expectation values, Wesley's quantum theory is not invalidated by the EPR argument.[14] In contrast, the de Broglie-Bohm[15] causal quantum theory, being merely a reinterpretation of traditional quantum theory, accepts expectation values as observables and thus is also invalidated by the EPR argument.

2. THEORY FOR THE EXPERIMENT OF ASPECT *et al.*

Aspect *et al.* use a source that radiates light in opposite directions. Within a coherence time of about 5 ns, the plane of polarization of the two beams remains in the same plane. The light in beam 1 is sent through a polarizer making an angle θ_1 with respect to beam 1 and is detected by a photomultiplier D_1. The other beam, beam 2, is sent through a polarizer making an angle θ_2 with respect to the same plane of polarization of beam 2 and is detected by a photomultiplier D_2. The singles counting rate per second registered by D_1 and D_2, according to classical physical optics, are proportional to

$$R(1) = \cos^2\theta_1, \;\; R(2) = \cos^2\theta_2, \tag{1}$$

assuming ideal polarizers and alignments. The number of coincident counts $R(12)$ to be expected classically is then given ideally by

$$R(12)/R_0 = \cos^2\theta_1 \cos^2\theta_2 + \cos^2\theta_2 \cos^2\theta_1 = 2\cos^2\theta_1 \cos^2\theta_2, \quad (2)$$

where R_0 is the number of coincidences with the polarizers removed. The factor 2 on the right arises from the fact that there are two ways a coincidence can occur. For a plane of polarization of the light yielding θ_1 for detector D_1 and θ_2 for detector D_2, from symmetry there must also be another plane of polarization of the light also giving a coincidence when the polarization is θ_2 for detector D_1 and θ_1 for detector D_2.

Letting

$$\alpha = \theta_1 + \theta_2, \quad \phi = \theta_1 - \theta_2, \quad (3)$$

the coincidence rate from Eq. (2) becomes

$$R(12)R_0 = (1/2)(2\cos\alpha\cos\phi + \cos^2\alpha + \cos^2\phi). \quad (4)$$

Since the original light beams are randomly polarized with respect to the polarizer over long times compared with the coherence time, the accumulated signal observed must be averaged over all α. This then yields the classically predicted result

$$[\langle R(12)\rangle_\alpha/R_0](\text{classical}) = 1/4 + (1/2)\cos^2\phi, \quad (5)$$

where ϕ from the second equation of Eqs. (3) is the relative polarization angle between the two polarizers that are before the two detectors.

According to Aspect *et al.*, traditional quantum theory predicts for ideal polarizers and alignments a coincidence rate given by

$$[\langle R(12)\rangle/R_0](\text{traditional quantum theory}) = (1/2)\cos^2\phi, \quad (6)$$

which differs from the classical prediction (5) by only 1/4.

3. EXPERIMENTAL RESULTS AND DISCUSSION

Aspect *et al.* claim that their "true" coincidence counts vary with the relative angle of polarization according to the traditional quantum theory prediction, Eq. (6) (assuming ideal conditions). In order to obtain the "true" coincidences from the total coincidences observed, they subtracted "accidental" coincidences. They do not present their data before subtracting "accidentals," nor do they present the classical optics result (5) that is necessary for comparison. They give no adequate explanation or justification for why they subtract "accidentals." They give virtually no information about the precise experimental magnitude of their all-important "accidentals."

They seem to have reasoned that the number of coincidences observed must have involved some "accidental" coincidences that did not involve simultaneously emitted photon pairs from single calcium atoms. In order to determine the number of such "accidental" coincidences, they measured the number of coincidences between the counts registered by one detector with the counts registered by the other detector after a long time (100 ns). After such a long time delay the coincidences observed could not possibly be associated with the photon pairs of interest, which are emitted simultaneously (within 5 ns). Thus they apparently reasoned that these delayed coincidences had to be "accidental."

The subtraction of these so-called "accidental" coincidences is not justified for the following reasons:

(1) With the limited detection efficiency of their setup, it is very unlikely that Aspect *et al.* were able to observe any "true" coincidences at all between pairs of photons emanating from the same calcium atom. Considering the reflections and absorptions in their optical setup together with the limited efficiencies of their photomultipliers, it probably takes from 10 to 100 photons to register a single count. For low light intensities, such as Aspect *et al.* use, radiation is known to occur as stochastic bursts[16-18] of clumps of many photons. Aspect *et al.* probably observed coincidence counts between such bursts, which do not involve photon pairs from single calcium atoms.

(2) Ordinary classical physical optics depends only upon the fact that the two beams are polarized in the same plane. The classical result (5) thus means that all the data must be retained as significant; no data can be discarded as "accidental." The classical theory does not depend upon any experimentally undemonstrable speculation about very unlikely coincidences between individual photon pairs that are supposed to emanate from the same calcium atom.

(3) The number of coincidences between photon bursts widely separated in time, which are uncorrelated in polarization and are thus "accidental," is not a measure of the lack of correlations for coincidences with null time delay, where the photon bursts are completely correlated in polarization and are thus completely "true."

(4) The classical rate of delayed coincidences, as given by averaging ϕ over 2π, constitutes part of the expected signal. It is large and cannot be regarded as "accidental" to be subtracted.

It is important to know the fraction of the total coincidences that Aspect *et al.* subtract as "accidental." Unfortunately, all that they say is: "Typical coincidence rates without polarizers are 240 coincidences per second; for a 100-s counting period we thus obtain 150 true coincidences per second ...."[3] They thus subtract about $90/240 \sim 1/3$ of their coincidence counts for null delay with no polarizers (equivalent to choosing $\phi = 0$) as "accidental." If the classical prediction, Eq. (5), is correct (and it undoubtedly is), then this means [setting $\phi = 0$ in Eq. (5)] that they subtract about $(1/3)(3/4) = 1/4$ from their original data as "accidental." In this way they convert the classical prediction (5), which they apparently observe, to the traditional quantum theoretical prediction (6).

It may thus be concluded that their original unmanipulated data fit the classical physical optics result (5) or Wesley's causal quantum theory and local causality far better than the traditional quantum theory result (6).

Papers[19] reporting similar experiments, such as the original experiment by Freedman and Clauser,[20] are not discussed here, because they contain insufficient information with regard to the "accidental" or "background" that is subtracted from the raw data to permit an adequate comparison with the classical physical optics prediction.

As expected from the classical theory or Wesley's causal quantum theory, the result should be independent of the distance between the two independent detectors, as observed by Aspect *et al.*[3] As expected from classical theory or Wesley's causal quantum theory, the result should be independent of switching the relative angle of polarization of the two independent polarizers while the two photon bursts are in flight, as observed by Aspect *et al.*[5]

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Résumé

On rapporte ici que Aspect, Grangier et Roger ont mal interprété leurs résultats expérimentaux à savoir qu'ils violent l'inégalité de Bell et que cette inégalité confirma la théorie quantique traditionnelle et le principe de non-localité. Ils rejettent abusivement des événements considérés accidentels. Lorsque ces événements sont retenus, les résultats obtenus confirment le principe classique de localité, en accord avec l'optique classique et avec la théorie quantique causale de Wesley.

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