Instant Communication : Induced Coherence with Coincidence Annihilation

© Thomas Alexander Meyer 2013

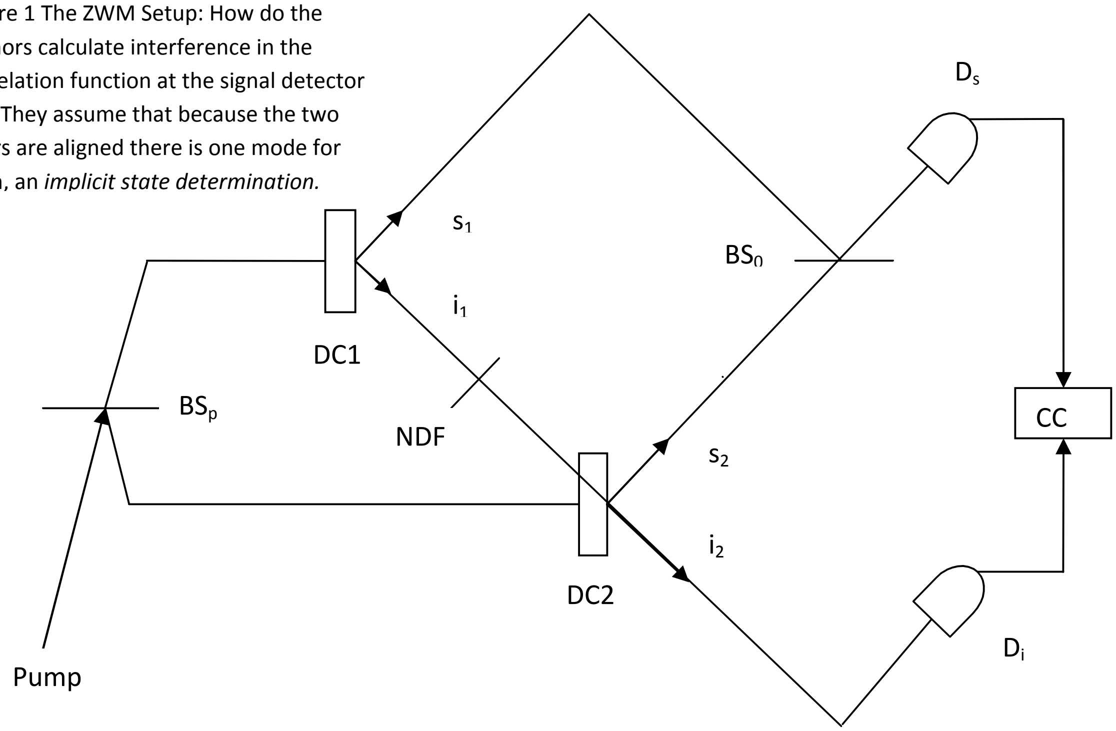
I propose a thought experiment which is intended to achieve the forbidden effect of instant action-at-a-distance by means of an action taken on a lone member of an entangled pair of downconverted photons. Single photon interference is achieved with the other photon of the pair because the action performed on the entangled partner has two consequences, induced coherence and coincidence annihilation.

The Out-Moded Assumption of No-Communication Theorem

The most noted of no-superluminality theories would be that commonly referred to as the *no-communication theorem* (or no-signalling theorem) of quantum mechanics. This theory assumes that the method of choice in producing instant communication would be to take an entangled system of particles and perform an action upon one which produces a measurable result with the other. With this assumption in mind, it is proven that it is not possible to produce such an effect by showing the method's inconsistencies with quantum mechanics. It is assumed in the theory that the action taken on the one member of the entangled pair is that of a measurement or operation. This assumption only presents the most trivial case of an action which may be taken, a simple measurement on one of the entangled pair. To put it bluntly, thisaction may*always* be explicitly described by our mathematical formalism of quantum mechanics. By looking at the trace of the total state operator over the possible results of theaction/measurement we arrive at the conclusion that there is no difference in the description of the entangled partner. The main problem that this theorem has is the assumption that the mathematical formalism of quantum mechanics is complete in explaining both of the action and in explaining the end consequences of the action on the total state operator. Obviously, there are laws of quantum mechanics that are not a part of the mathematical formalism of quantum mechanics, as there is the law of quantum mechanics that describes indistinguishability in interference effects and the dependence of interference on the state description of the interfering system which is in turn dependent upon a lack of path knowledge. This law is specifically notused by the theoretician in a manner that may be described as an explicit mathematical operation but rather it is a part of the implicit state determination process.

In quantum mechanics, when we assign the state description of the system we always take into account the preparation of the system and make an informed decision on what the most appropriate description is. This is called the state determination process, and here we like to categorize this process in two sub-categories; the *explicit state determination* process and the *implicit state determination* process. In the state determination process one must always take into account the preparation and associated with this preparation will be the source and the set of mathematical operations and measurements which will give you the most appropriate state vector of the specific system at any point in its time evolution. This is the explicit state determination process. Also in the state determination process one must take into account the amount of information of the system that is implied by the preparation, this is the implicit state determination process. Specifically in the case of interference effects, one must look for indistinguishability of paths and it might be very rare, but on occasion the indistinguishability is itself not a consequence of and not explainable with the explicit state determination, it is only implicit in the preparation. We recall a specific example of experimental optics where the indistinguishabilityin the interference experiment is implicit in the preparation, and the author of the paper refers to this indistinguishability when they decide to treat the state description of the system appropriately. This would be the physicist making the decision to change the state description based upon the presence of indistinguishability in the preparation, rather than it being the case that there is a mathematical explanation for the change of state description based upon the preparation.

Figure 1 The ZWM Setup: How do the authors calculate interference in the correlation function at the signal detector D_s? They assume that because the two idlers are aligned there is one mode for both, an *implicit state determination.*



The ZWM (References 1 & 2)

These papers[1,2] present an experiment with induced coherence between the outputs of two separate photon downconversions, typically referred to as signal and idler photons, which is demonstrated by the presence of single photon interference between the two possible sources of signal photon. The experimental setup is illustrated in Figure 1 where a pump wave is beam split (BS_p) into two coherent pump beams that are made incident upon the two separate non-linear optical crystals (DC1 and DC2). The pump photon is an Argon-Ion laser with wavelength 351.1nm and the downconversion crystals are non-linear $LiIO_3$ crystals which occasionally convert the laser pump photons into a signal and idler pair. The signal (788.7nm) and idler (632.8nm) photons created in downconversion obey a wave vector conserving process so that their frequencies add to the pump frequency. The output idler beams are setup to be in exact alignment which requires that the first idler i_1 be transmitted through the second crystal DC2 where it comes into alignment with i_2 and both beams are incident upon a time resolved detector D_i. The signal outputs are added at second beam splitter (BS_o) beyond which they fall on a time resolved detection system D_s. The experimental arrangement is setup so that the optical paths from the pump beam splitter to the second crystal (BS_p to DC1 to DC2) and (BS_p to DC2) is less than the coherence length of the pump light (5cm). Also the optical path lengths of (DC1 to BS_o via s_1) and (DC1 to DC2 to BS_o via i_1 and s_2) are made to differ by no more than a coherence length of the downconverted light (0.33mm). There is also a coincidence counter (CC) which is used to compare the counts registered by the two detectors to check for coincidence counts.

With this setup the authors conduct interference experiments by varying the path difference of the signal paths and collecting the counting rate at D_s as a function of path difference. They perform this interference experiment for several different values of transmissivity of the filter which is placed in the path between DC1 and DC2. This filter is actually a set of neutral density filters which can be added to reduce transmissivity. By performing the interference experiment for several different values of transmissivity they find a linear relationship between the visibility of the interference and the transmissivity. One is lead to the obvious question, why would the interference between the possible sources of signal have a dependence upon the preparation of the idler? The quick answer is to simply state that the knowledge of the path of the signal is made available to the experimenter if the idler is blocked. If there is downconversion at DC1 and idler i_1 is blocked then there should be a signal photon detected at D_s which came from DC1 and there should be no detection at D_i because the idler was blocked. If there is downconversion at DC2 then we get detection at both detectors D_s and D_i in coincidence. So when the idler is being blocked the idler detector gives us information of the path of a signal photon detected at D_s; the path is s_1 if there is no coincidental detection at D_i and the path is s_2 if there is a coincidental detection at D_i. This is the conceptual account of the experiment provided by the authors but we must also understand the experiment in the context of a mathematical analysis provided by the authors.

In the theoretical analysis of the ZWM setup the authors of the study begin with the interaction Hamiltonian for the interactions at the two downconversion crystals. They treat the neutral density filter (NDF) as a beam splitter with an empty input port. The authors calculate a time dependent state vector as

$$
\begin{aligned}
|\psi> = {} & |0>_{s_1} |0>_{i_1} |0>_{s_2} |0>_0 + f(t)|1>_{s_1} |1>_{i_1} |0>_{s_2} |0>_0 \\
& + g(t)\{T|0>_{s_1} |1>_{i_1} |1>_{s_2} |0>_0 + R|0>_{s_1} |0>_{i_1} |1>_{s_2} |1>_0\}
\end{aligned}
$$

with four terms in total, and each indicating the presence of two photons in two of four possible modes, except the first term which is the vacuum state. The four modes are subscripted as s_1, i_1, s_2&0 and the T and R represent the transmissivity and reflectivity of the NDF beam splitter respectively. The *f(t)* and *g(t)* are functions with time and phase information. You might be wondering what mode is *0*? It is the vacuum input port mode of the beam splitter that replaced the NDF. You might also be wondering what happened to the second idler mode i_2?This is where indistinguishability comes into play. The authors make the assertion that the two modes of i_1 and i_2 are to be treated as one mode on the condition thatthey are exactly aligned. Now, I do not in my humble wisdom as a physicist wish to suggest that the authors are wrong in any way here, in fact I whole heartedly agree with them. There is a legitimate reason to treat the two idler modes as one, and it is the indistinguishability of the two idlers which is the reason for this treatment, and one might note that there is no way for the authors to get around this interjection in the state determination process. If they wish for the state vector to yield an interference term in the calculation of the correlation function at the signal detector, then they must have a state vector with one mode for both idlers. On the other hand, if the two idlers are not aligned (or if i_1 is attenuated by the NDF) then the authors would not treat the two idler modes as one. In this case the state vector would have two distinct idler modes and no extra vacuum input mode of the beam splitter and with such a state vector they certainly would not get an interference term in the calculation of the correlation function at the signal detector.

Emission and Measurement Indistinguishability

So what is the difference between the two, alignment and non-alignment of the idler beams? Certainly all of us have seen other examples in QM experiments where there is indistinguishability of optical sources, but this did not warrant the dropping of a mode in the calculation of the state vector. Why so in this case? This type of indistinguishability is what I like to call *emission indistinguishability*. In order for two sources of a photon to be considered indistinguishable they must first have identical state descriptions, there can be no part of the state description which would indicate a distinction between the two. But technically this only makes them identical, not definitively indistinguishable. When the indistinguishability between two possible sources of a photon results from the emission of one photon field taking place at the exact time that the second photon field is transmitted through the region of the emission of the first, and there is exact alignment of the two photon beams, then the two possible sources of the photon have emission indistinguishability, assuming of course that the two possible photons are also identical. The other more common category of indistinguishability is *measurement indistinguishability*; at the time of measurement the multiple possible sources of the particle are permanently indistinguishable. This measurement form of indistinguishability is often present in QM experiment and it is the central concept in such effects as interference and recombination. This form of indistinguishability does not necessarily require that the sources of the particle be identical (they do not need to be identical if there is no post-measurement indistinguishability) but only that the multiple possible sources of the particle are not in any way distinguishable as the exact source of the photon (no path information).

So what about the ZWM experiment and the emission type of indistinguishability? A good way to look at things is that the emission type is a form of indistinguishability that arises at the time of the birth of the photon, whereas the measurement type takes place only at its death. If the indistinguishability of two possible sources of a photon is the result of one source having emitted at the time that the other identical source would have its photon transmitted through the region of the emission and in alignment with the emission, then the two sources are emission indistinguishable. This indistinguishability between sources of a photon is not only relevant for the final detection moment of the photon, but for the whole lifetime of the photon after emission, meaning that the indistinguishability has to be taken into account in the state determination of the system, meaning that the state description is *updated* at the time of the emission. This is why the authors of the ZWM study were entitled to treat the two modes of the idler photon as a single mode, because they were emission indistinguishable. They were practicing what we have earlier referred to as the implicit state determination process. They were making an assessment of the preparation and realized that the explicit mathematical state determination was incomplete, there was something about the preparation of the idler beams that was very relevant to the determination of the state description but that could only be implicitly noted, that which we refer to here as emission indistinguishability.

With all this having been said, we might be of the impression that the ZWM (Figure 1) has a sequence of updates to the state description of different systems as time goes by in the experiment. At the time of emission of the first signal and idler the state of the combined system would only include a vacuum state mode and the first signal and idler modes s_1 and i_1. At the time when the possible idler i_1 would arrive at the second crystal (approximately the same time that the pump photon would have reached the second crystal) there should be an update of the state description to the four mode state which the authors calculate. This is said to be contingent merely upon the alignment of the two idler beams, but is this misleading? The calculated state vector is also contingent upon a delayed “choice” or preparation concerning the signals, namely the addition of the signals at the signal detector. Properly stated, the calculated state vector is contingent upon measurement indistinguishability of the possible sources of the signal photons. At times after the downconversion at the second crystal there is still the possibility of distinguishing the idlers by virtue of a measurement of the signals (which would mean that the implicit state determination, the dropping of the second idler mode, would be wrong). The signals must eventually be combined with measurement indistinguishability in order for the state description to apply. One might argue that the authors would not mention this point simply because the calculated state vector is only meaningfully applied in the authors’ analysis at the time of the detection at the signal detector. The authors calculate the correlation function at the signal detector with use of the time dependent state vector. The authors do not apply their calculation to times prior to this detection.

What About Instant Communication?

So what does all of this have to do with instant communication? Well, the most obvious demonstration of non-locality in physics is the presence of EPR states or entangled states. As was earlier mentioned, no-communication theorem claims that these states cannot be used for the purpose of instant communication on the grounds that no action could be taken on one member of an entangled system which has measurable consequences on its entangled partner. This reasoning is sound in as far as it assumes that all possible actions that could be taken are also actions that can be modelled by the explicit state determination process. And we have clearly demonstrated that there are actions, namely the preparation for emission indistinguishability, which could be taken on one member of an entangled pair which would have consequences on the determination of the state of the whole entangled system. Although it is to be noted that we used the example of the ZWM which requires actions at both ends, emission indistinguishability at the idler end and measurement indistinguishability at the signal end. This leaves us begging the question, could such an action on one member of an entangled pair (emission indistinguishability) have not only consequences on the state determination for the combined system, but more importantly could such an action have consequences on the measurable statistics of the entangled partner, without requiring action on both ends? Could we prepare a lone member of an entangled pair for an action like emission indistinguishability, or a similar action which determines an implicit state determination, in a manner that the action instantaneously affects the partial state operator of and the measurable statistics of the entangled partner? At this point we can only suggest a thought experiment which will test this exact query.

The Instant Communication Protocol

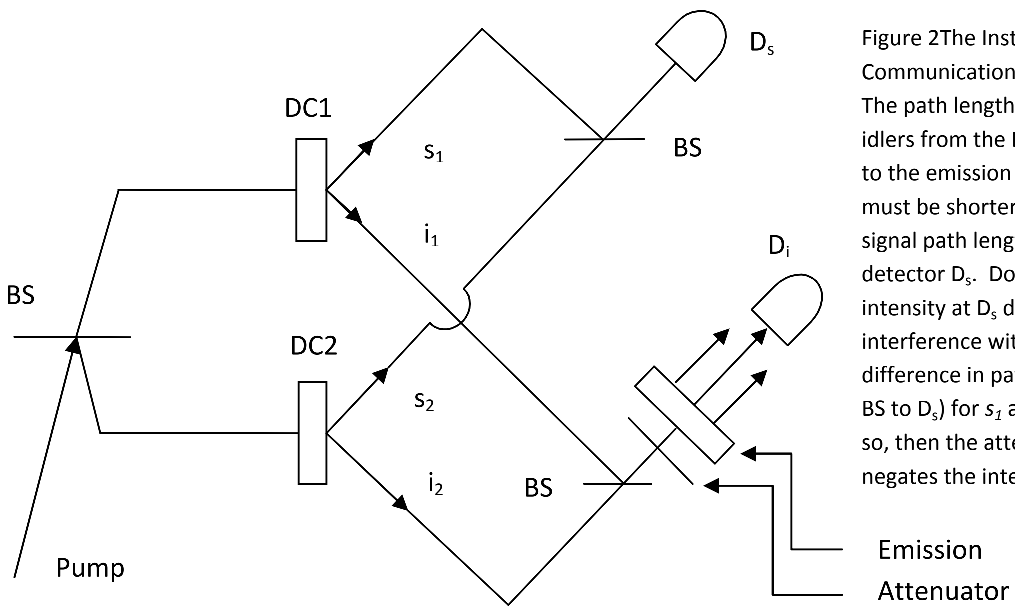


Figure 2The Instant Communication Protocol: The path lengths of the idlers from the DC crystals to the emission source must be shorter than the signal path lengths to the detector D_s. Does the intensity at D_s display interference with the difference in paths (pump BS to D_s) for s_1 and s_2? If so, then the attenuation negates the interference.

In Figure 2 we propose a protocol for instant communication based upon the above explanation of emission indistinguishability. The setup begins from the bottom left where the pump laser is beam split (BS) to pump two downconversion crystals DC1 and DC2. The two downconversions are assumed to be identical to those of the ZWM. The two signal beams are combined at a beam splitter and made incident upon detector D_s. The two idler beams are also combined at a beam splitter and made incident upon detector D_i. Just prior to the detection of the idlers, the combined idler beam is incident on a variable attenuator and transmitted through an emission source. The optical path lengths are arranged so that the length from a given downconversion crystal along the signal beam to the signal detector is longer than the length along the idler beam to the emission source. The path length from the pump beam splitter to D_s via s_1 and the path length from the pump beam splitter to D_s via s_2 differ by no more than a coherence length of the signal photons, Δx_s. All put together we have;

Path(DC1 to D_s along s_1) > Path(DC1 to Emission along i_1)

Path(DC2 to D_s along s_2) > Path(DC2 to Emission along i_2)

$|\text{Path(Pump BS to DC1 to } D_s) - \text{Path(Pump BS to DC2 to } D_s)| \leq \Delta x_s$

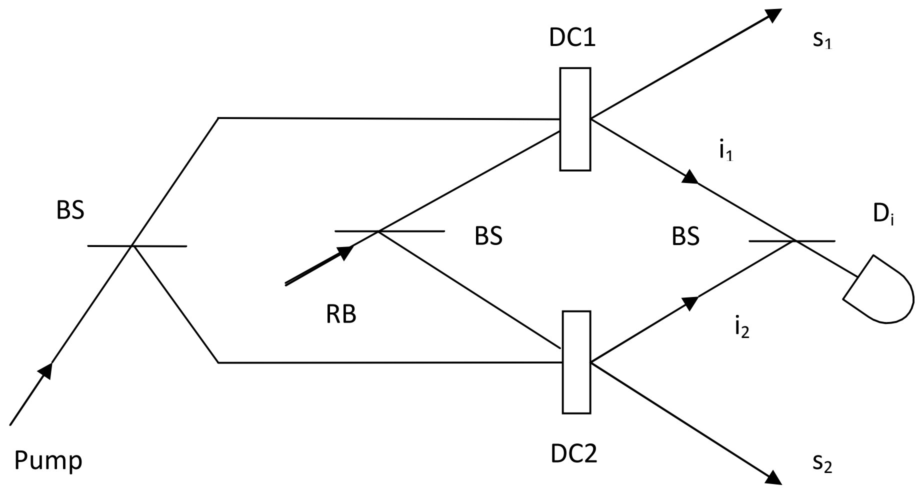
The emission source is emitting a beam of photons that is aligned with the mixed idler beam and the total mixed output is incident on detector D_i. The photons that are emitted by the emission source are identical in description to the idler photons. This preparation of the mixed idlers and the emitted photons would constitute *emission indistinguishability* as we have defined it above. Of course, the attenuation may block the idlers from reaching the emission source, so the emission indistinguishability is contingent upon the idlers passing the variable attenuator. The emission source could be from a solid state crystal with photoluminescence that matches the idler description. The exact apparatus used for the emission source doesn't need to be defined here and we assume it would be a simple matter to prepare an emission which is identical in description to the idlers.

The WZM: Coincidence Annihilation (References 3 & 4)

With this total preparation in Figure 2 we notice that one would still be able to distinguish the idlers in the combined beam exiting the emission source by virtue of comparison to the detected signals. One would not be able to distinguish between idlers i_1 and i_2, but one is able to distinguish the idlers of i_1 and i_2 from the emitted photons that are identical to them. This means we cannot get interference at D_s, so how do we propose to get by this problem? By quenching the idler beam with the emission source. One cannot simply emit a beam of photons that are identical to the idlers and similar in intensity to the idlers and in alignment with them, one must *quench* the idler beam by emitting a beam of photons with a photon occupation number that far exceeds the combined photon occupation number of the idler beams. This way one not only satisfies the expectation of emission indistinguishability but also satisfies another criterion that I like to call *coincidence annihilation*. By adding an emission to the idler beam which is far greater in intensity than the idlers, one is negating the possibility of identifying the idlers by virtue of a coincidental detection with the signals. When the idler beam is quenched with identical emitted photons there is no longer any ability to distinguish which photon of many coincidental idler photons is the originally entangled idler. If this seems unbelievable then I would ask you to read on because a similar effect is used by the authors of the ZWM in an earlier paper on the subject of interference between idlers with induced emission in downconversion.

This analysis is based upon a pair of published papers[3,4] from 1989 to 1990 where the first paper (the OWZM) presents the theoretical analysis and the second paper (the WZM) presents the experimental verification. In Figure 3 we illustrate the WZM which takes its name from the ordering of the authors in the second published paper, the experimental verification. The setup has a pump beam which is split by a beam splitter (BS) where the two outputs pump the downconversions at two non-linear optical crystals (DC1 & DC2). The four downconverted photon beams of signal and idler are arranged so that the two idlers are added at a detector, D_i, where we look for single photon interference. The peculiar difference with this setup is the presence of a reference beam (RB) which has a similar description to the signal photons (both are 632.8nm). The reference beam is beam split to be transmitted through both crystals in a manner that it is exactly aligned with the outgoing signal beams. Because the reference beam is identical to the signals and it is of sufficiently strong intensity, the reference beam "induces stimulated downconversion" of signal and idler pairs. The induced emission has the property (which is the case for all examples of induced emission in optics) of inducing coherence between the inducing field and the emitted field. This is a big change in the mathematical picture of downconversion, as the signal and idler of the induced emission are now mutually coherent, which would not otherwise be the case. In addition, the split reference beams are coherent and they are each inducing emission in one downconversion crystal, so the outputs of the two downconversions are also mutually coherent. All put together, the four outputs of the two downconversions are coherent. So adding the two idlers could produce a coherent combination which displays spatial interference. This is all contingent upon the initial assumption of the setup; that the reference beam is of a sufficient strength of intensity.

Figure 3 The WZM: Why is there interference at the idler detector when the coincidental signals may be measured to infer the path of the idlers? Because the signal beams are quenched by the reference beam, *coincidence annihilation*.



The authors perform a complete calculation of the state vector and the correlation function at the idler detector which gives its counting rate. They begin with the time dependent state determination where it is assumed that the total state vector for the combined system is a product of two state vectors pertaining to the two downconversions. Each of the state vectors for downconversions 1 and 2 have a similar treatment which results in a state vector with two terms. There is a term of high probability with the vacuum state for the idler mode and a coherent state, the state of the reference beam, for the signal mode. The second term is of much lower probability and it is for the occupied state which has the idler and signal modes occupied, and the signal mode is in the coherent state of the reference beam. This is important in calculating the correlation function at the idler detector, because the state of the signal modes for each possible term in the total state vector is occupied with the coherent state. For a normal downconversion state vector calculation this would not be the case, there would be a vacuum state for the signal mode in the high probability terms. This use of the coherent state, the state of the reference beam, for the signal modes for all terms is justified because of the induced emission, as the state of the signal beam is always assumed to be the coherent state. Of course this will then lead to a calculation of the correlation function at the idler detector which yields an interference term which is a cosine with an argument of the difference in the two optical paths from a crystal to the detector.

For us, the relevant result of the paper is that this interference with optical path difference at the idler detector D_i has a visibility related to a single ratio, which in the words of the authors of reference 4 is described as "...the average photon occupation number (of injected reference beam photons) per mode of the inducing field." The condition is that this ratio be much greater than 1. This is better explained in a final quote of the authors in reference 3, "It is only when the stimulated emission dominates, that the injected signal beams induce coherence between the two idlers." The point the authors are getting at is that the inducing field is of sufficiently high intensity that the induced emission dominates the spontaneous emission and only under these conditions does the interference become visible. But is there a different way of interpreting this condition that would be in keeping with the theme of this chapter? What about indistinguishability? Should we interpret this paper in such a context even though the authors clearly explain all their results with the appropriate calculations? In the ZWM paper by the same authors they seemed to place great emphasis on the concept of *in principle knowability*, specifically the knowability of path of the interfering photon that may be inferred from the knowability of the path of its entangled partner. Of course, the ZWM was published after the WZM so it might not have been a priority for them to understand the WZM setup in the context of knowability until they had reached definitive conclusions concerning the relevance of distinguishability, conclusions which could only be arrived at in the ZWM. Whatever the explanation, I definitely would argue that there is much more going on in the setup of the WZM that concerns indistinguishability and I will elaborate on this now.

In the WZM, you have an induced emission which has to be the dominant emission in order to get highly visible interference. The visibility condition is related to a ratio of the average photon occupation number of injected reference beam photons, *N*, to the bandwidth of the reference beam, Δv. The bandwidth of the reference beam is the same as the bandwidth of the signal beam, which is the inverse of the coherence length of the signal beam, $1/\Delta v = \Delta x_s$. The condition for visibility is

$$N/\Delta v \gg 1 \qquad \text{or} \qquad N\Delta x_s \gg 1$$

So the photon occupation number of the reference beam must be large and the coherence length of the signal must also be large. How do we understand this in a manner different from the authors of the WZM? We must think of distinguishability in the context of downconverted*pairs*. For each interfering idler there is a coincidental signal photon which may be measured to infer the path from which the interfering idler originated. So how could it be that the idlers will display single photon interference when such inferential information is available to the experimenter? Because the inferential information isn't actually available. Why? Because of what I have earlier referred to as coincidence annihilation, as clearly the above condition for visibility also indicates that there must be a large enough coherence length for the signals that there is guaranteed to be no way to distinguish the signal as being in coincidence with a specific idler. If we look at the above relation, $N\Delta x_s \gg 1$, it states that the *number of reference beam photons per path length* multiplied by the *path length per signal photon* is large. This is identical to saying that the number of reference beam photons per signal photon is large. (I have assumed here that the WZM uses entangled photons which are only coincidental to within a time delay which is on the order of the coherence length of the signal and idler. When entangled particles are exactly *spatially* entangled it may be shown that neither has a finite momentum uncertainty, whereas when entangled particles are exactly entangled in *momentum* it may be shown that the positions of the particles are not exactly entangled but rather that they are entangled to within their respective uncertainties in position. In the case of the WZM the setup uses momentum entangled particles which obey the wave vector conserving equation where the signal and idler wave vectors add to the pump wave vector. Because the signal and idler are momentum entangled I have assumed that the two are only coincidental to within a coherence time of the signal photon.)

The injection of the reference beam not only induces emission of the downconversion but it also causes coherence between the outputs of the downconversions because it quenches the signal output in a manner that the signals may no longer be measured to give meaningful coincidence with the idler. The idlers of the downconversion are isolated, but could we measure these idlers in coincidence with the signals in a way which would infer the path of the idler from the presence of the signal on a specific path? No, because there are too many reference beam photons per signal that are mixed together in an indistinguishable manner such that you cannot determine which of the signal or reference beam photons is in coincidence with a given idler. There would be many photons in the mixed signal/RB beam that are in coincidence with a given idler detection, ergo the coincidences are not meaningful. This criterion of coincidence annihilation contributes to the fulfillment of the criterion of measurement indistinguishability at the idler detector D_i. Once the idler is detected at D_i where the two idler beams are overlapping, there is no way to distinguish between the paths of origin of the idler, it is a setup with measurement indistinguishability. This would not otherwise be the case had the signals still been distinguishable, had the criterion of coincidence annihilation not been fulfilled for the signal and idler pair.

For any who might wish to disagree with the argument presented in this section, coincidence annihilation, I would ask how they would explain the lack of significance of the *in principle knowability of the idler's path by virtue of a measurement of the signal* in the WZM experiment? How would others explain away the fact that the idler's path should in principle be measurable by virtue of a measurement of the signal? The authors of the WZM did not address this concern and for that reason I would suggest to the reader that the complete explanation is in no way trivial or obvious.

Completing the Picture for the Instant Communication Protocol

So how does all this apply to our earlier mentioned thought experiment that we called the Instant Communication Protocol illustrated in Figure 2? We would ask what happens at the signal detector D_s? If all arguments we have proposed in the current writing are sound then we should expect that the state description of the combined system is "updated" at the time the mixed idler beam reaches the emission source. Assuming the attenuation (A) is nil, all idlers reach the emission source and the emission indistinguishability criterion would seem to be fulfilled, because the downconverted idlers are transmitted through an "idler-like" emission at the time of the emission and in alignment with the emission. But by this reasoning alone we would still have the ability to distinguish between the downconverted idlers and the emitted "idler-like" photons of the combined beam by comparing the detections at the idler detector to the detections at the signal detector for coincidences. Coincidence counts between the two would tell us that the idler detection is from one of the downconversions and not from the "idler-like" emission. But, if the "idler-like" emission is of sufficient photon occupation number (intensity) to constitute coincidence annihilation between the idlers and signals then there is no meaningful coincidence between the idlers and signals of downconversion. Specifically, with coincidence annihilation we require that the photon occupation number of the "idler-like" emission is far greater than the photon occupation number of the mixed idler beam that resulted from the downconversions, and the coherence length of the idlers is large enough to ensure that there are many "idler-like" photons that are coincidental with any given idler of the original entangled signal and idler pair. And it is important to note that this fulfillment of coincidence annihilation takes place at the time of the "idler-like" emission, the same time as that of the emission indistinguishability, the time of the update of the state description.

All put together we would expect that these criteria would warrant our suspicion that the appropriate state vector for the combined system (to be evaluated for the time of emission indistinguishability onward) should only include a single mode for the mixed beam which includes the two idlers and the "idler-like" emitted photons, as there is no possible way to distinguish between the three sources of this beam after the time of coincidence annihilation. If there is only one mode in the state vector, then a calculation of the correlation function at the signal detector should yield an interference term for the two possible sources of a given signal photon, s_1&s_2. The intensity at D_s will show interference while varying the optical path difference |Path(Pump BS to DC1 to D_s) - Path(Pump BS to DC2 to D_s)|. If this is indeed the case and there is single photon interference at the signal detector that is contingent upon the emission indistinguishability and coincidence annihilation, then the attenuation (A) of the mixed idler beam will attenuate the visibility of interference at the signal detector. This effect would translate instantaneously across the distance between the two detectors. The only delay would come as a result of the path difference (pump BS to D_s) - (pump BS to attenuator). This delay is minimised by placing the attenuator/emission at the furthest possible point allowed by the path conditions.

Closing Remarks

Regardless of whether the IC protocol we have suggested works or not, there is a definite argument to be made here that indistinguishability and the implicit state determination process might possibly be used for a protocol which gets by the no-communication argument. The implicit state determination process is being considered by the authors of the ZWM, a consideration which they were forced to take because of the preparation of the ZWM setup which is not explainable with the explicit state determination process assumed by the no-communication theorem. We also consider the case of coincidence annihilation, for which the WZM preparation is an example. Such a preparation of coincidence annihilation may be used to contribute to an implicit state determination.

Our main conclusion in this writing is that the no-communication theorem is only sound if one assumes an explicit state determination. There definitely exists possible preparations of entangled photons where the state determination is implicit and it is not achievable with mere mathematical means because the reasoning of the theoretician must intervene. This possibility allows for one to consider different thought experiments where one aims at preparing an action which may be taken on a lone member of an entangled pair which has measurable effects on its entangled partner. It may be that the thought experiment which I have suggested in Figure 2 will fail to produce such an effect, but that should not discourage others from considering thought experiments of a similar form. The general form of thought experiment should seek to achieve the same end goal as the ZWM and WZM, a single photon interference effect from the possible sources of a lone member photon of an entangled pair, but it must also seek to provide an action on the other member of the entangled pair which will determine the presence of the interference effect, an action that when not taken will negate the interference from a distance. Obviously this action could be a preparation for emission indistinguishability, a preparation for coincidence annihilation or a combination of the two.

References

1) X. Y. Zou, L. J. Wang, and L. Mandel, *Induced Coherence and Indistinguishability in Optical Interference*, *Phys. Rev. Lett*., 67, 318 (1991).

2) L. J. Wang, X. Y. Zou, and L. Mandel, *Induced coherence without induced emission*, *Phys. Rev. A*, 44, 4614 (1991).

3) Z. Y. Ou, L. J. Wang, X. Y. Zou, and L. Mandel, *Coherence in two-photon down-conversion induced by a laser*, *Phys. Rev. A*, 41, 1597 (1990).

4) L. J. Wang, X. Y. Zou, and L. Mandel, *Observation of induced coherence in two-photon downconversion*, *J. Opt. Soc. Am. B*, 8, 978 (1991).