Were EPR correct after all; did Bell miss a point?

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**Abstract**

There is still much controversy in quantum mechanics over the concept of local reality and entanglement but this concept is, surprisingly, somewhat neglected by philosophy suggesting that philosophy has here let slip an opportunity. This paper argues that the theoretical background to Bell’s inequality overlooks a fundamental coordinate determination. If a coordinate factor for polarization or spin is included, Bell’s theoretical probabilistic inequality for correlation between the parts of an entangled system is changed to a probability that agrees, instead of disagreeing, with experimental results. Einstein’s objections to indeterminacy and apparent lack of locality reality would then be upheld.

Keywords: EPR-Bell, entanglement, local reality, determinism, quantum mechanics.

**1. Introduction**

Quantum theory is renowned for its peculiarities, not the least of which is the loss of local reality, and determinism. These concerns were raised by Einstein, Podolsky and Rosen (EPR) in 1935 whereby they suggested that the quantum mechanical formalism derived by the so-called Copenhagen Convention (Bohr, Heisenberg, Schrödinger and others) was incomplete. Einstein was always worried by the conflict between his intuition, the probabilistic nature of quantum theory, and in particular the latter’s apparent conflict with reality – a concept that has led to even greater conflict with human perception, for example, the world being made of things that are not real (attributed to Bohr cf Leggett 2002:419) or the universe needing to be observed for it to exist (d’Espagnat 1979:158, Rees 1987:46, Mermin 1981:397). For many the matter seemed settled by Bell’s inequality theorems (1964, 1975) which apparently overcame the objections raised by EPR.

Despite a number of tests apparently confirming Bell’s assessment, there is still no complete agreement between physicists over the exact form of the quantum mechanical (QM) rejection of local reality, causality and determinacy. But, surprisingly, philosophers have accepted this rejection rather than EPR’s dissension. Ladyman and Ross (2007:1,4), for example, go a step further using naturalistic metaphysical arguments that philosophy of science should accept such loss of local reality and determinism and proceed from the laws produced by physicists rather than trying to determine what these laws should be. On page 175, for example they are quite specific that their arguments fit with “cutting-edge physics”. Other philosophical contributions either report on the two sides of the EPR-QM argument (Butterfield 1992, Norton 2011, Evans, Price and Wharton 2013) accepting that QM deals with concepts below our vision; or they debate arguments by physicists on variations over technical aspects of entanglement, such as wave collapse or many world theories (see e.g. Maudlin 2007 § 4, 5, Vongehr 2011, Fankhauser 2017, Karakostas 2012).

I believe the mere acceptance of the peculiar ideas following from QM does not agree with the philosophical tradition of disputation. As de Haro (2013:8) says, contrary to Ladyman and Ross: “One of the tasks of philosophy is to scrutinize the concepts and presuppositions of scientific theories, to analyze and lay bare what is hidden and implicit in a particular scientific paradigm.” I also agree with Einstein: reality and determinacy are necessary to our existence[[2]](#footnote-2), so I here investigate Bell’s inequality calculations from a more visual and spatial rather than mathematical approach. Only two aspects need be explored: the nature of the correlation (hidden variable or instruction set), and the physical aspects of the tri-variable sample space used by Bell, Mermin (1981, 1985) and Preskill (2019 Chapter 4). These aspects lead me to conclude that Bell omits a fundamental coordinate determination which, when taken into account, reverses his inequality. This outcome would imply that, contrary to Bell’s assertion, Einstein’s local reality and determinacy requirements are preserved.

Sections 2 and 3 briefly explain EPR’s objections and Bell’s probabilistic counter to them. In particular, Bell’s inequality is expanded with the aid of a detailed approach by Mermin (1981, 1985). Sections 4 and 5 discuss possible experimental loopholes, the nature of bipartite entanglement, polarization and Stern-Gerlach spin. These concepts raise the necessity of a coordinate system to both clarify (a) the experimental results with special relevance to reflection of spin and polarization, and (b) the correlation of a bipartite entanglement. This discussion passes from sections 5 through to 7, demonstrating that the theoretical inequality calculations by Bell, backed by Mermin and Preskill, are flawed in the extent that (1) the calculations should have included a coordinate system to specify the polarization/spin states of the entanglement, (2) as a result of this failure the inequality calculations do not reflect the complete physical situation and (3) if (1) and (2) are taken into account Bell’s, Mermin’s and Preskill’s theoretical calculations would agree with the experimental tests and not the inequality.

**2. Einstein, Podolsky and Rosen query.**

EPR (1935:777) first asked the important questions of any physical theory, is it correct and is it complete? This is, of course, the basic concern of all the literature on the subject. In particular, for completeness, EPR presumed that physical theory should lead to reality (which is a subject in itself, because human senses depend on superficial observation with no certainty that what we see or hypothesize is actually true in a universal context). EPR related reality to the certainty of a theory’s prediction, noting that in QM this is fundamentally obviated by Heisenberg’s uncertainty principle. Thus they arrived at “(1) the quantum-mechanical description of reality given by the wave function is not complete or (2) … two physical quantities [with non-commuting operators] cannot have simultaneous reality.”

They then cited a two-part (entangled) system in which either part should be measurable independently of the other. Here a wave function for each of the two parts could be superimposed, whereupon, according to the uncertainty principle, two different outcomes could belong to the same reality. This dual outcome, they asserted, implied that there can be no exact statement of a *real* underlying situation at a specific instant (1935:778). Our act of measuring would become the determining factor thus reducing any *a priori* state (probability of a particular property) acquired by the part being measured to having only a chance of affecting the outcome of that measurement. What might be called ‘the reality of its existence’ would be lost. Consequently EPR concluded that the wave function is not complete (1935:780) and that quantum mechanics (QM) needed amending. Bohm (1952:abstract) subsequently suggested the possibility of a hidden variable (HV) to overcome the problem.

**3. Bell’s theorem 1964 and 1975 with Mermin’s 1981 and 1985 interpretation.**

The first clear rejection of EPR’s sentiments was formulated mathematically by Bell (1964), and subsequently revised for the 1975 GIFT seminar[[3]](#footnote-3). These led to experiments conducted over the period 1981 to the present (see e.g., Zeilinger 1999; Aspect, Grangier and Roger 1981; Reid et al. 2008; or earlier tests such as that of Freedman and Clauser 1972 for cascade electron hidden variable experiments). However, I shall take a thought experiment by Mermin (1981, 1985) which explains very clearly the general principle contained in Bell’s papers (1975§5:7-9 and 1964). Mermin’s approach is used because it allows easy comparison of the fundamental factors between the experimental and theoretical outcomes, and, in particular, the relation between Bell’s theorem and the ‘reality’ of entanglement versus EPR’s objection. A similar argument in favour of Bell’s results is included in Preskill (2019) – see sections 6-7 below.

The general concept that Bell considers is a pair of particles, *A* and *B*, that at some time, *t*o were correlated (entangled in a joint light-cone) for a given property, for example Stern-Gerlach spin or photon polarization. These particles separate far enough (with space-like motion in Bell’s assessment) that tests can be conducted on them outside their original joint light-cone; that is, a test on particle *A* can be conducted for the given property, followed by one on particle *B* shortly afterwards, but before any information travelling at the speed of light from *A* could have been passed on to *B*. Then the outcome of the separate measurements can be compared, with each measurement being independent of the other. In particular, *A* could be either spin up or down (in the case of half-integral spin), knowledge of which is unknown until a measurement is performed on *A*. At this stage, according to QM theory, the measurement outcome is determined by an interaction between the measuring equipment and *A* – which is sometimes referred to as causing a collapse of the wave function (Muthukrishnan and Roychoudhuri 2009); a second measurement follows for part *B* before any information of the outcome of the measurement on *A* could have passed to *B*. Thus it is impossible that the outcome of the measurement of *B* could have been fixed specifically by the outcome on *A*, nor could it have been fixed on the *outcome* on *A before* the test on *A*. However, Bell theorized, using probability theory, that predictions could be made for the outcome of a series of tests based on whether or not there is a causal relationship between the bipartite states.

Briefly, Bell’s calculations are divided into two parts. The first determines the probabilities, or expected outcomes, of a set of such experiments on the assumption that the particles carry a causal correlation between them (his 1964 paper considered the allied concept of hidden variable, HV, type correlation). The second part calculates the expected outcome according to QM theory (*i.e.* no correlation or HV) and predicts a different outcome to the first set. Thus experiments can be run to see which probability is reflected in nature: that of QM theory as given in the ‘Copenhagen’ interpretation, or EPR’s concept that the theory is ‘missing something’ – an HV or other correlation (which Mermin (1981) interpreted as an ‘instruction set’ IS).

Mermin has provided the following theoretical background for experiments to test Bell’s theorem. Suppose two particles (*A* and *B*) travel from their source in opposite directions with no possibility of contact between them or their origin after emission. Mermin (1981: 403) requires “that the various states or conditions of each particle can be divided into eight types: RRR, RRG, RGR, RGG, GRR, GRG, GGR, GGG” (amended in Mermin 1985 to be recorded in corresponding recording equipment). Suppose these codes represent a total possible state for each particle, and R and G refer to a particular condition or constituent in that state, for example, in the case of an electron, state spin up or down; or, in the case of a photon, state left or right circular polarization (LHP and RHP respectively); more of the particular condition later. Neither the state (spin up, spin down et cetera), nor the property carried by each R and G is known prior to measuring either of the photons (or other particles). In order to achieve experimental randomness, each measuring device has a switch that can be randomly set to any one of three positions independently of the experimenter. A first measurement can be made for either particle, say the left (*A* in Figure 1), and a second measurement for the right, *B*, any time thereafter – but in keeping with Bell’s requirement that these two measurements are made completely separately so that no collusion between the two can occur. On the arrival of the photon at the measuring device, it triggers a Red or Green light to flash according to whether the constituent part of the state is represented by R or G, and whether the device has been switched to setting, 1, 2 or 3. For example, suppose the left device receives its particle first, and was randomly set to switch 2: if it flashes green it is noted as 2G. Similarly, the other recorder flashing later on receipt of particle *B* may give 3R – colour red with switch set randomly to 3. The trial is run thousands of times and the recordings listed. If in Mermin’s (1985:46) test system the recorders are both set to the same switch, they always record the same colours, e.g. 22GG where if one constituent G stands for coding spin up or, say, LHP, the other G stands for spin down or RHP – i.e. if say, RRG for one recorder stands for spin up, RRG on the other is spin down; and, still using RRG as an example, for settings 1 and 3, the codes would give different colours, 13RG.

O

*z*

*y*

*x*

*A*

*z*

*y*

*–z*

*+x*

*B*

*z*

*–x*

Figure 1. One possible entanglement format; A photon arrives at O and is reflectively ‘split’ (see section 3) to give two entangled parts *A* and *B* which move apart back to back as for a reflection.

According to this formulation it is possible to calculate the probable statistical outcome of the experiment. For example, if the particles carry an ‘instruction set’ that can be coded RGG, the switch may be set to 1, 2, or 3 so that the result will be, say, 1R from one recorder and maybe 3G from the other. Neglecting the possibility of the sets RRR and GGG for the time being, the possible outcomes of each run (for the set RGG) are 11RR, 12RG, 13RG, 21GR, 22GG, 23GG, 31GR, 32GG, 33GG from which it is easily seen that the probable outcome is 5/9 that each recorder will record the same colours. A similar result occurs for the other mixed colour sets (*e*.*g*. RRG, GRG etc.). If RRR and GGG are included then the expectation values of same colours being observed for these two cases are 9/9. That is, if both particles *carry the same ‘instruction set’* the same numbers will always give the same colours in the experiment, *e.g.* 1R,1R (see Table 1).

Overall, the probability of obtaining these same colour results from the two recorders if an IS exists should be 48/72 or 2/3 as given in Mermin (1981:402) (see also Table 1 below). Mermin (1985: 9; 1981: 403) claims that there is no other possible theoretical expectation if the photons carry an IS and follow this coding system. On the other hand, if there is no IS or HV, the calculated expected outcome becomes ½. So, as Bell suggested there is a difference in the expectations depending on whether an IS/HV is present. The actual experiments (see Zeilinger and others above) over a very large number of runs, and repeated with different methods, always yields ‘same colour results’ very close to ½ , that is 36/72. Thus, as expected according to QM theory, the experimental results do not match the theoretical HV/IS predictions, *i.e.* they “violate” the expected results for a correlation between *A* and *B*.

According to Mermin (1985:9), an IS cannot be constructed in such a way that the same colours are recorded half the time as found in experimental tests. The conclusion must then be that there is no original IS or HV to determine the outcome; the outcome of the experiment is determined by the interaction of ‘measuring’ the photon. Consequently, Bell, Mermin, Zeilinger, and others, interpret the experimental tests as refuting the two EPR assumptions of determinism and local reality. I shall now argue a different interpretation of the HV/IS predictions that agrees with the experimental results and thus allows Einstein’s local reality.

**4. Re-examination of the theory and Bell’s theorem**

First, some essential problems should be considered, which I contend lead to a necessary reassessment of Bell’s inequality in relation to EPR. These are not concerned with details of the experimental evidence but with the fundamental concept of this relationship – considerations that should have been investigated by philosophers in accordance with de Haro (2013:8). Thus I will first assume that the experiments can be made free of any ‘loopholes’ (see *e*.*g*. Shimony 2009 §4-§5). The equipment is assumed to function faultlessly so that there can be no contact between *A* and *B,* or their source of entanglement, as they travel in opposite directions from the source. This would include that the sum of *A* and *B*’s individual state values, at and after creation, is assumed to be evenly balanced with those of the source at their joint creation, or interaction in the case of other particles. That is, there is no change in the total energy of the system from the instant before interaction until the measurement on *A* is made; and then that this measurement has no effect on the remaining part *B* until *B* is measured – it being understood that the result of these measurements involves only the interaction between the measuring apparatus with the individual part being measured. In other words, the experiment is isolated from external influences except in the measurements. Moreover, if, say, two photons, *A* and *B*, being generated from a common source are to be similar, they must each correspond to equal parts of the original parameters: for example, half the input energy or momentum, as dissimilar energy or momentum could be interpreted as a ‘loophole’. That is, due to the uncertainty principle, there could be no certainty that *A* had not changed one or more of its quantum states independently of *B*, or vice versa – the assumption being that any initial HV/IS conditions (given by λ in Bell 1964 :195-6) apply to both *A* and *B*. The same goes for entanglement of spin-½ particles. For photons the entanglement may be through polarization: for, example left or right circular.

A further question arises on the nature of the ‘split’ in the case of photon pairs, which does not appear to have been established in the literature: Are the subparts separate entities or an extension/ development of a holistic system over a period of time? For example, Couteau (2018:7) refers to a single photon split into two, which could make sense since experiments achieve a measurement of each part, *A* and *B*, at different times. But Ashok & Roychoudhuri (2015:abstr) find the divisibility of a photon an “open question”, while Reid *et al.* (2008:2) refer to spatially separated particles. Alford (2016:1) notes that superposition implies that the parts still form a singlet state. On the other hand, according to quantum theory as developed and experimentally tested, entanglement in the QM sense means allowing each part to acquire a conditionally separate existence in order to attain the mathematically required superposition. And it also allows that the two parts can be measured separately. Yet, based on the assumption that we are investigating a single whole isolated from any external influences, *A* and *B* must be connected in the sense that each must remain faithful to the original conditions. Without this proviso, tests would be unable to arrive at a firm conclusion on QM conceptualization. Therefore, if the two parts could be recombined, in a thought experiment for example, at any time before measurement of one of them, they would have to give back the original source. It seems, then, that the actual condition of holism versus separation is unimportant, as both (holism and separation) should give the same outcome. Consequently I shall refer to either ‘*A*’ or ‘*B*’, or ‘parts’ of the (bipartite) system, and proceed without being concerned whether they are separated or part of a whole.

Finally, the question of R and G. Mermin (1985:7) suggested they could stand for anything, for example, a cube, a circle or tetrahedron depending on the colour combination. In whatever way R and G are taken, each coding position must represent a specific part different from that represented by another, so that if RRR stands for a cube, RRG might be the sphere, RGG the tetrahedron, GGR an octahedron and so on for the eight possible arrangements. Thus not only the colour balance is important in his calculations but the interpretation, for example 2R will alter the overall meaning from say 2G; 2R could represent part of a sphere or part of a cube and 2G a tetrahedron or octahedron, and so on. This may seem obvious here, but I shall show later that this is not so obvious in Mermin’s inequality calculations (and again I point out this method is not Mermin’s own, Bell (1975) and Preskill both use arguments based on three two-choice components). Mermin associates RRR with one polarization (or spin) according to one of the receptors, and RRR for the opposite polarization at the other receptor, but does not define the meaning of R or G specifically. This failure leads to a serious loophole in his inequality calculations. But to show this, it is first necessary to analyze the nature of polarization (or Stern-Gerlach) reflections, and then to derive a set of definitions that will clearly represent the bipartite system.

**5. Relativistic image**

If the system under investigation is holistic then this results in the two parts being what I shall call ‘*relativistic images*’ of each other as described below. On the other hand, if the system is split into two separate photons connected only by the source conditions (*N* in Bell’s paper) they must also, to maintain the original specifications, be relativistic images of each other, so holism or separation makes no difference in this case either.

By ‘relativistic image’ I mean the following. If we look into a mirror everything we see becomes reversed horizontally w.r.t. ourselves. If we point our right hand thumb towards the mirror then the fingers form a right hand (RH) screw. But the image in the mirror reverses the thumb direction in our view to make it the equivalent of a Left Hand (LH) screw. But note that the rotation itself does not change direction, it is only the thumb which points out of the mirror that indicates the LHS condition. Now take the source particle, O in Figures 1 and 2, with, say, LH circular polarization LHP, seen from its direction of travel as anti-clockwise, and let it split. The two parts must rotate in the same direction; that is, let one travel along a *z*-axis in the +*z* direction in which case it has LH rotation seen as anti-clockwise from its source, O in Figure 1. Then the other must travel with the same rotation but this will be in the opposite, right hand (RH), clockwise direction (as seen from the source), it travels in the –*z* direction from the source, as otherwise the actual rotation of one part would have to physically change direction requiring energy to do so. This would require an extra energy input as the source photon split, contrary to the above conservation of energy assumptions. Thus the only difference between the parts and the source is the direction of propagation of the two parts *A* and *B*. To be clear, an external (to the bipartite system) and overall observation coordinate system is required, given here as (*X*, *Y*, *Z*) arbitrarily taken in Figure 2 as coinciding with *A*’s local coordinates. *A* and *B* then move through this system; experiments carried out on the two parts can only be carried out according to the experimenter’s frame of reference, taken here as the (*X*, *Y*, *Z*) system. From this overall coordinate system looking along the +*Z* axis coinciding with the +z axis of the *A* part, the rotation has not changed. But for each part, in terms of its *local* axis, *A* ‘would see’ his rotation (circular polarization) still LHP, and *B* would ‘see’ his own rotation RHP. Thus one part appears as a reflection of the other. But each looking back to the other would not notice a difference between their rotations – hence my term ‘relativistic image’, in analogy with Einstein’s time dilation effect between two observers. We thus have the equivalent reflection of the quantum ‘beables’ in Bell’s paper, or properties in Mermin’s, without any actual change from the original source rotation. This connection between the two parts, I suggest, then forms the instruction set. That is, the instruction set is merely the quantum ‘beables’ or state of the original particle before the bipartition.

*Y*

*X*

*Z*

*z*

*y*

*x*

–*x*

*A*

*z*

*y*

+*z*

*–x*

+*x*

*B*

*A* local coordinate system

*B* local coordinate system

Observer’s coordinate system

*z*

*y*

*x*

–*x*

O

(a) (b)

Figure 2. O has circular polarization along its *z*-axis at the instant it ‘splits’ into two parts *A* and *B* which separate parallel and anti-parallel to O’s *z*-axis. These are shown with *local* coordinates according to each frame of reference. The directions of the axes are compared to an overall observer’s coordinate system *XYZ*. Hence we see for *B* that –*z* corresponds to *Z*, *y* corresponds to *Y* and *–x* to *X*. Note that this diagram is only an arbitrary representation as *A*’s polarization is unknown until a measurement is made, and this measurement only gives the result of the measuring interaction in accordance with the observer’s coordinates.

It is clear from this form of reflection, or relativistic image, that a coordinate system is essential to evaluate the experiment. Indeed Preskill (2019 Ch 4:24,25) refers to coordinates although Bell and Mermin do not. The mere act of ‘splitting’ the system into two parts travelling in different directions creating LHP and RHP requires a different spatial description for each. Then, for a particle being ‘split’, measurements made of either part, *A* or *B*, can produce nothing more than its state at the time of measurement. Such a measurement cannot reveal the state of the original particle either before, or even at the time of its ‘split’ because we do not know whether *A* or *B* actually carries the same polarization (or other testable property) as the original particle – I only assume it is *A* for the sake of presentation. The entanglement can then only make sense within the ambit of the actual ‘split’. Measurements made later, as in the tests, are subject to the interaction with the measuring process, and therefore it can be said that Heisenberg’s uncertainty principle (a) applies to the possibility of the measurement determining the outcome – that is determining, for example, the measured polarization of a *possibly* causal (in the sense of local reality, determined, or *a priori*) state for each part; and (b) it causes an uncertainty about the states of *A* and *B* before they are measured. Therefore, it is doubly essential to consider a coordinate system when calculating how the ‘beables’ relate to the tests.

Nevertheless, if an IS or HV should exist for the entangled system, then the IS/HV must have been ‘imported’ with the original source. Consequently, whether the source provides two separate particles or a holistic system, the instruction set must be divided by the separation – it does not seem reasonable that everything else in the system except the instruction set could be divided. Furthermore, it does not seem reasonable that the instruction set for, say, circular polarization with one part observed as carrying LHP and the other RHP, could be identical for both parts. But there can be no disputing that the polarization appears different in the two parts (turning RHP through 180° still leaves RHP) so the instruction set must be relevant to the spatial conditions, that is, the direction of travel in relation to the source of the entanglement. And from Figures 1 and 2 it can be seen that calling one side LHP and the other RHP is meaningless unless coordinates are attached to their relevant parts.

Apart from the above objections there is another extremely important consideration. The recording system itself must register the chosen property, for example circular polarization. This property, to be correctly registered, will require its own spatial system to allow for the interaction that causes the registration. That is, the recording system will record in its own coordinate system. At the end of section 4, I specified the necessity of defining R and G. For the sake of simplicity I designated the recording system with a set of (*X*, *Y*, *Z*) axes fixed in the same direction as the left hand part, *A*. Then, since the properties are given by Rs and Gs in Mermin’s example, I shall associate R with positive *x*, *y*, *z*, and G with their negative directions. Thus, for example, LHP for *A* in Figure 2 would give RRR and *B* would be GRG. This is different to Mermin (1985:9 and Fig8) who for example, in 22RR, associates the first R with one polarization and the second R with the opposite polarization. I make this difference only in the sake of clarity and only for analyzing the theoretical calculations.

No doubt, quantum physicists might object to the use of coordinates, and perhaps this is a reason why such an interpretation of the test given here has not been advocated before. According to Heisenberg’s uncertainty principle only one beable can be measured at any one interaction. Consequently they might claim that, if one coordinate is known (is measured) then the others become uncertain; if, for example, *xA* records as R, *yA* and *zA* would be unknown (Bohm and Aharonov 1957:1070). This uncertainty should be clearly irrelevant in this situation because rotation, or circular polarization, is spatially orientated so that if the coordinates are unknown, so too must be the handedness of the polarization and the direction of travel. Therefore the only uncertainty is the direction of the polarization for *A* and *B* until measurement is made, whereupon the polarization determines the coordinates, or equivalently R or G.

**6. Reasessment of Bell, Mermin, Preskill inequalities.**

This is where, I believe, in *support* of Einstein, an error in judgment by his critics may have been made. The measurements of *A* and *B* are made in the experimenter’s (observer’s) frame of reference, which frame must be exactly equivalent for both recorders. *The measuring interaction then takes (transforms) the local systems of A and B into the observer’s/recorder’s system*. As this is external to the colour coding I will ignore the coding system for the next few sentences. Thus *A*’s and *B*’s local coordinate systems must conform to that of the experimental frame, one or both of *A* and *B* being ‘re-labeled’[[4]](#footnote-4) as necessary so that its coordinate system (and thence colour coding) is correctly expressed in the observer’s system. In terms of their local axes (as in Figure 2), *A*’s rotation is in the sense of a point on *A*’s *y*-axis rotating anti-clockwise (as seen from the origin) towards the *x*-axis – and thus agrees with the overall *XYZ* system whereas in terms of *B*’s local coordinate system, a point initially on *B*’s *y*-axis rotates towards *B*’s –*x-*axis (clockwise as seen from O) which in the recording frame’s (*X*, *Y*, *Z*) coordinate system would be the same as a point initially on *B*’s +*x*-axis rotating towards the *y*-axis (*i.e.*, *y* to –*x*), see Figure 3. Thus, for the ‘relativistic image’ in terms of the (*X*, *Y*, *Z*) system, as in Figure 2b, the –*z* coordinate corresponds to *Z*, *y* corresponds to *Y* and *–x* to *X*. Returning to the colour codes that I have suggested above, Bell’s beables or Mermin’s properties would be correlated to the coordinates arbitrarily as R for a positive coordinate in terms of circular polarization and G negative, RRR for *A* then becomes GRG for *B*. In Mermin’s system where he judges on similar colours he would give RRR for both *A* and *B*.

*y*

+*z*

*–x*

+*x*

*B*

(a)

*Y*

*X*

*Z*

*y*

*-z*

*x*

-*x*

*B*

(b)

+*z*

*–z*

Figure 3. Diagram (a) compares *B*’s local system in the experimenter’s *XYZ* frame of reference.

Converting it to the *XYZ* frame gives diagram (b) representing the opposite circular polarization to part *A*. In terms of Mermin’s colours and my colour-coordinate correlation, the polarization codes as GRG opposite to RRR either way.

The point, to be made absolutely clear, is two-fold. First, there must be a geometrical transformation from the local frames of reference to the experimental frames of reference which is achieved, not by changing the rotation, but by a previously unperceived/unused change in the spatial coordinates – it being born in mind that the coordinates are merely an invention of the human mind to describe physical conditions. The rotation (the physical condition) itself cannot change between the two parts without an energy input into one of the parts, instead it is a ‘correction’ to the coordinates that is required as in Figures (2-3). In the case of the ‘entangled relativistic image’ with change of circular polarization as in section 5 (or up-down spin for spin-½ particles), the so-called IS or HV should be considered in terms of the spatial differences caused by the ‘split’. That is, the ‘split’ itself would manifest Bohm’s proposed HV or IS, in which case the supposed HV/IS becomes synonymous with (or replaced by) the expression of the coordinate systems derived above. An IS/HV ‘knowing’ beforehand that it must produce different properties for the two parts for a possible experiment seems absurd. The IS/HV *follows* from the original particle, or system, and should therefore be balanced between the two parts so that as a whole it corresponds to the properties of the original particle. Consequently, as suggested, the triconditional sample space system, when expressed in terms of an entangled bipartite system, must refer to a 3-dimensional coordinate system.

Secondly. This is where the difference in interpretation appears because Mermin codes the opposite polarization for RRR as RRR, or for GGG by GGG at the separate recorders. But from the Figures, by using opposite colours for opposite polarizations, (which is easy enough to adapt to Mermin’s method as he *arranged* his two receptors to both flash red for opposite polarizations) RRR clearly becomes opposed by GRG. Exactly the same applies to Stern-Gerlach spin. Similar calculations to Mermin’s, but using opposite colours for opposite polarizations (as given in Table 1 row 4) produces same colours only 3/9 times as opposed to Mermin’s RRR-RRR calculation, which gave 9/9 same colours.

Here, the flaw in Mermin’s calculations becomes apparent – and the same triconditional sample-space system is referred to by both Bell (1975) and Preskill (2019). The choice of RRR-RRR is obviously made to use ‘same colour’ for ease of his (Mermin’s) description but, although the RRR-RRR coding seems plausible, it is in fact misleading as Figure 2 demonstrates. The argument is most palpable by first using opposite colours for opposite polarizations, or spins, at the receptors. From Figure 2 (and Figure 3) the *y­* and *Y* axes have the same physical meanings; but the propagation directions (± *z*) for *A* and *B* are different, and similarly, the polarizations (rotation of +*y* towards either ± *x*) are different. Thus in a coordinate coding system RRR (for ­*zyx* and Z*YX*), *Y*/*y* is R for both *A* and *B*, but in *B* the difference of polarization or spin is reflected by G for ­– *z* and G for *–* *x*. The coding then becomes RRR for *A* and GRG for *B* as quoted earlier. That is R:R means same physical conditions, R:G means different physical conditions for a given coordinate, or Mermin’s properties. In Mermin’s coding system R is used for the separate recorders irrespective of the of the property differences (1985:9 and Fig8). Thus RRR always couples to RRR and gives the same colours for switch settings 11, 22, and 33. But it is now clear that *the different physical meaning of the middle R has been lost* – whether or not it relates to a coordinate system; in Mermin’s system the two outer Rs stand for polarization (or up/down spin) *differences* between the recorders, but the middle R should stand for identicalness, not difference. His calculations should then only read 6/9 for same colour. Therefore his claim for same colours 9/9 times is spurious. The same goes for GGG and RRG *et* *cetera*. It appears, then, that his 2/3 result *follows from his colour coding*, not *from the actual physical conditions* it is supposed to represent. This flaw is sufficient to falsely raise his (and Bell’s) overall *theoretical* probability for finding IS/HV correlation from ½ to 2/3 – see Table 1.

Note: (1) that the introduction of a coordinate system has no effect on the RRG type of probabilities because the opposite to RRG is not GGR, but as shown in Figure 4b, GRR so same colour probability is still 5/9 for these sets. (2) that similar arguments apply to particles both propagating in forwards or both propagating in backwards directions. In this case, as above, their rotation, or helicity, must be the same as that of their source. This is possible if their local axes are arranged as in Figure 4b. And (3) that Preskill and Bell (1975) both used the same tri-conditional sample space as a preliminary basis to their inequality arguments.

*B*

*z*

*x*

*y*

*z*

*A*

*z*

O

*-x*

*z*

*-y*

*z*

*y*

*x*

RRG

*z*

*y*

*x*

*-x*

*A*

RRR

GRR

*-z*

*y*

*x*

*-x*

*B*

 (a) (b)

Figure 4. (a) The reflection/relativistic image *B* of *A* in the *XYZ* coordinate system; RRG becomes GRR. (b) The local coordinates for *A* and *B* in terms of the original source axes which are in the same directions as *A*’s; reflection of *A* into *B* at 45° to the *y-*axis along the *z*-axis .

To complete the argument for reconsidering Mermin’s (and Bell’s) calculations, the expected outcomes can be tabulated as follows:

Table 1. Mermin’s calculation sets.

Second row: the state RRG for different settings in Mermin’s thought experiment with the top and bottom settings (RRG and RRG) producing the same colour combinations (RR) in columns 1 and 2, and different in column 3 (RG), *etc*. Similar sets can be obtained for the other 5 possible colour options RGR, RGG, GRR, GRG, GGR giving an overall probability of ‘same colour occurring’ of 6 lots of (5/9) = 30/54.

Third row: GGG and GGG or RRR and RRR will always give same colour combinations.

Fourth row: Using opposite colours for differences the probability for obtaining the same colours from RRR/GRG is 3/9 and similarly for GGG/RGR, giving for the relativistic image only 6/18.

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| States | 1 1 | 1 2 | 1 3 | 2 1 | 2 2 | 2 3 | 3 1 | 3 2 | 3 3 | Total for all |
| Same RRGDifferent RRG |  1 1 | 1 2 | 1 3 | 2 1 | 2 2 | 2 3 | 3 1 | 3 2 | 3 3 | 6 × (5/9) |
| GGG & GGGRRR & RRR  | Same | Colour | for  | All |  |  |  |  |  | 9/99/9 |
| Same RRRDifferent GRG | 1 1 | 1 2 | 1 3 | 2 1 | 2 2 | 2 3 | 3 1 | 3 2 | 3 3 | 2 × (3/9) |

 Total for same colours (Mermin’s probabilities) + RRR/RRR + GGG/GGG = (30+18)/(54+18)

 Total for same colours (Corrected probabilities) + RRR/GRG + GGG/RGR = (30 + 6)/(54+18)

Thus the use of a coordinate system produces an expectation of (30 + 6)/(54+18) =1/2 not 48/72 = 2/3.

Although the table gives all Mermin’s possibilities, it is only necessary to consider his RRR system (opposite polarization/Stern Gerlach GRG) and his RRG for which the opposites (my colour codes) are easily seen to be GRR (Figure 4a) – RRG and GRR give 5/9 probability of same colour. The other colours are analogous, as can easily be seen by drawing a diagram; for example, GGG is equivalent to RRR upside down.

Finally, it is worth noting that Figure 3b is in line with Caltech’s QM lecture notes (Preskill [1998 §4.1.4:148-150] 2019) who, unlike Bell, is specific about coordinate axes). Preskill just did not make the connection between the coordinates and Bell’s λ for the HV factor see section 7.

These observations suggest that the *theory* behind the experimental tests is not complete: (1) it has been created to test only the case of identical supposed instruction sets (i.e., the instruction set is considered identical *after* the ‘split’ instead of being taken *before* the ‘split’); (2) it has not taken into account the possible nature of an instruction set; and (3) nor has it considered the role of the coordinate systems in determining how the calculations should be applied.

**7. Reassessment of Bell 1964 and1975 and Preskill 2001**

Bell’s papers are divided into sets of equations (1964 equations 1-12, 1975 equations 1-16) describing theoretical calculations for the experimental expected outcomes of a HV theory; and thereafter a proof (equations 13-22 and 17-24, respectively) showing the result does not agree with QM’s expected outcomes. I refer to Preskill’s (1998: §4.1.4 pp10-12) presentation as his is coordinate specific whereas Bell’s is not.

According to both Bell and Preskill the hidden variable *λ* is taken as deterministic for the fundamental local reality system applying to the bipartite state. *λ* is therefore expected by them to be the same for both parts *A* and *B*. Section 6 above, together with the figures, suggest on the contrary that *λ* should be taken, not as a hidden variable in the case of the bipartite state, but as specifying the coordinate system between the relativistic images (or reflections as the case may be) of the two parts. Thus, returning to the standard QM concepts, as expressed by the second part of Bell’s papers, Preskill’s *defined* travel direction (1998: 11) for the photon is ± *z* with polarization in the *xy* plane giving the coordinate structure (*x*, *y*, *z*) for *A* and (–*x*, *y*,–*z*) for *B*. This is the same formulation as in Figure 3. Thus *λ* should be given correspondingly different coordinate signs when referring to *A* or *B* and should not be treated the same for both *A* and *B*.

**8. Conclusion**

The so-called instruction set, or hidden variable, is merely the original set of predetermined physical *and spatial* properties of the particle *before* splitting. The spatial properties are always relevant so that the bipartite split determines two sets of spatially differentiated properties. A standardized coordinate system is therefore a necessity for determining the theoretical correlated expectations of a bipartite entangled EPR system. The resulting calculations would change Mermin’s (and Bell’s) expectations to give ‘probability of same colours’ as ½ and not 2/3 as originally thought. This probability (½) agrees with the experimental outcomes and suggests that correlation between the coordinate system and the test quantum states should also have been applied to Bell’s theoretical calculations through his factor λ. Therefore, under the circumstances suggested, the statement: ‘that the non-attainment of a probability of approximately 2/3 for repeated runs of the experiment shows that the result is determined by observation interactions independently of each other’, and ‘that there is no instruction set’, is false. Consequently, reality and determinacy, as suggested by EPR, are indeed preserved, and this is doubly true as the reality of the experiments overcome the falsity of the original quantum calculations.

Allowing that the above has been a valid objection to QM indeterminacy and loss of reality, it seems reasonable to recall de Haro’s (2013:8) statement on the task of philosophy as analyzing the ideas of physics. Unfortunately, however, it does not settle the matter of Einstein’s position on QM incompleteness. The allied QM versus classical problems of the double slit and delayed choice experiments are evaluated in work under preparation, the result of which provides classical solutions to these problems and confirmation of Einstein’s wish for ‘reality’.

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1. \* University of South Africa, Department of Philosophy . email john.fredrick.thompson@gmail.com [↑](#footnote-ref-1)
2. “[I] *cannot believe that we must abandon, actually and forever, the idea of direct representation of physical reality in space and time*;” (Einstein [1940]: 334) [↑](#footnote-ref-2)
3. Bell’s 1964 theorem included hidden variable theories which were shown by Kochen and Specker (1967) to be contradictory to quantum mechanics theory. [↑](#footnote-ref-3)
4. This does not mean the coordinates may be arbitrarily changed. If one looks at Figures 1 and 2 in combination and considers the standard arrangement of axes, a reflection is shown in Figure 1b with the *x*-coordinate maintaining the same sign as that of part *A.* But *B*’s local coordinate system to have the same spatial arrangement as A’s must be as in Figure 2b. This is not the same spatial arrangement as the *XYZ* axes of the recording instruments so the correct description connecting *B* to the recorder is as in Figure 3b. [↑](#footnote-ref-4)