Modelling the Effects of Entanglement

D L Mentz [1]

January 9, 2018

1. Introduction

This note presents a non-local 'hidden variable' theory of the photonic EPR experiment. The probability distribution and a simple algorithm given are sufficient to predict experimental results. All the probabilities and correlations of interest can be can be calculated from the probability distribution and the computer code merely confirms that it could be generated by a simple process.

Entanglement enters the probabilities through the non-local assumption that the entangled pair always have the same polarization angle irrespective of the physical context.

2. The Ideal EPR Experiment

Considering an ideal experiment where symmetrically entangled photons are sent in opposite directions from a common source to polarizers and detectors A and B. The recorded results are the polarizer settings and detector clicks or no-clicks from A and B. See [1]. In every run the settings of polarizers A and B and the order (S) in which A's and B's photons interact are randomly set with equal probability for each value. The prepared photons are assumed to have the same polarization orientation on every run. This can be relaxed to allow small random deviations that do not significantly affect the results.

From the following additional assumptions we can deduce the probabilities $P_{xy}(\alpha, \beta, S)$ where x and y are 0 (no click) or 1 (click) and α and β are the polarizer settings at A and B respectively and $S = (A, B)$ is the order variate.

1. The entangled pair always have the same polarization orientation
2. If either photon passes through a polarizer (click) then they are both projected into the polarizers setting
3. If a photon does not pass (no click) then the entanglement is broken and the remaining photon is not affected.

If A's photon interacts first this gives (with $\theta_A \in [a, a']$, $\theta_B \in [b, b']$ and θ_0 is constant for all runs)

$$P_{11}(\alpha,\beta,A) = \cos\left(\frac{\theta_A-\theta_0}{2}\right)^2 \cos\left(\frac{\theta_A-\theta_B}{2}\right)^2,\ P_{10}(\alpha,\beta,A) = \cos\left(\frac{\theta_A-\theta_0}{2}\right)^2 \sin\left(\frac{\theta_A-\theta_B}{2}\right)^2$$

$$P_{01}(\alpha,\beta,A) = \sin\left(\frac{\theta_A-\theta_0}{2}\right)^2 \cos\left(\frac{\theta_0-\theta_B}{2}\right)^2,\ P_{00}(\alpha,\beta,A) = \sin\left(\frac{\theta_A-\theta_0}{2}\right)^2 \sin\left(\frac{\theta_0-\theta_B}{2}\right)^2$$

If B's photon interacts first

$$P_{11}(\alpha,\beta,B) = \cos\left(\frac{\theta_B-\theta_0}{2}\right)^2 \cos\left(\frac{\theta_A-\theta_B}{2}\right)^2,\ P_{10}(\alpha,\beta,B) = \sin\left(\frac{\theta_B-\theta_0}{2}\right)^2 \cos\left(\frac{\theta_A-\theta_0}{2}\right)^2$$

$$P_{01}(\alpha,\beta,B) = \cos\left(\frac{\theta_B-\theta_0}{2}\right)^2 \sin\left(\frac{\theta_B-\theta_A}{2}\right)^2,\ P_{00}(\alpha,\beta,B) = \sin\left(\frac{\theta_B-\theta_0}{2}\right)^2 \sin\left(\frac{\theta_0-\theta_A}{2}\right)^2$$

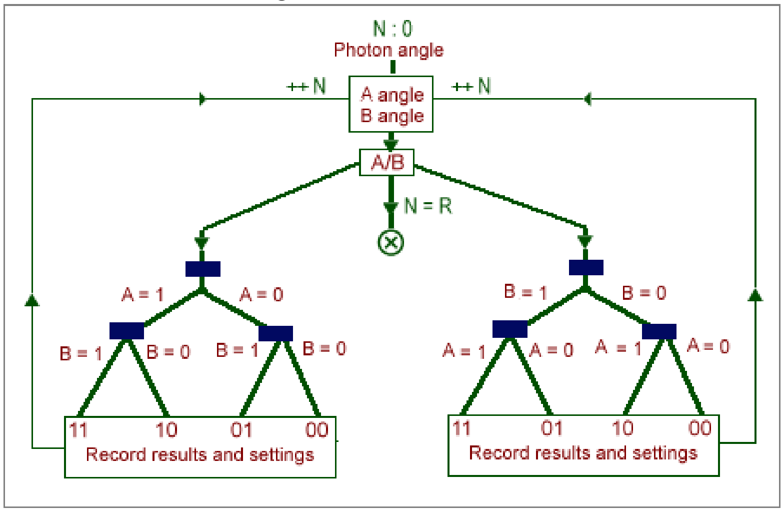
[1] mentz114@hotmail.com

Summing over S gives $P_{xy}(\alpha,\beta) = \frac{1}{2}\left(P_{xy}(\alpha,\beta,A) + P_{xy}(\alpha,\beta,B)\right)$

3. **The Simulation**

The simulation uses the four rules in section 1 and performs a Malus law projection twice in each repetition. The virtual apparatus is assumed to be perfect. There is no doubt that the simulation is

Figure 1: Code Flowchart



reproducing the joint probabilities $P_{xy}(\alpha\beta)$ with remarkable fidelity, without using them explicitly.

4. **Discussion**

5. **Appendix**

The value of the Clauser-Holt/Eberhard statistic is given by

$$\begin{aligned}
2\mathcal{L} = &-cos\left(\frac{b'}{2}-\frac{\theta_0}{2}\right)^2 cos\left(\frac{b'}{2}-\frac{a'}{2}\right)^2 - cos\left(\frac{a'}{2}-\frac{\theta_0}{2}\right)^2 cos\left(\frac{b'}{2}-\frac{a'}{2}\right)^2 \\
&- cos\left(\frac{a}{2}-\frac{\theta_0}{2}\right)^2 sin\left(\frac{b'}{2}-\frac{a}{2}\right)^2 - cos\left(\frac{a}{2}-\frac{\theta_0}{2}\right)^2 sin\left(\frac{b'}{2}-\frac{\theta_0}{2}\right)^2 \\
&- cos\left(\frac{b}{2}-\frac{\theta_0}{2}\right)^2 sin\left(\frac{b}{2}-\frac{a'}{2}\right)^2 + cos\left(\frac{b}{2}-\frac{\theta_0}{2}\right)^2 cos\left(\frac{b}{2}-\frac{a}{2}\right)^2 \\
&+ cos\left(\frac{a}{2}-\frac{\theta_0}{2}\right)^2 cos\left(\frac{b}{2}-\frac{a}{2}\right)^2 - sin\left(\frac{a'}{2}-\frac{\theta_0}{2}\right)^2 cos\left(\frac{b}{2}-\frac{\theta_0}{2}\right)^2
\end{aligned}$$

References

[1] Johannes Kofler, Marissa Giustina, Jan-ke Larsson, Morgan W. Mitchell
Requirements for a loophole-free photonic Bell test using imperfect setting generators
`https://arxiv.org/pdf/1411.4787.pdf`

[2] Marissa Giustina, [...], Anton Zeilinger
A significant-loophole-free test of Bell's theorem with entangled photons
`https://arxiv.org/pdf/1511.03190.pdf`

[3] H. Bernien, B. Hensen, W. Pfaf,G. Koolstra, M.S. Blok, L. Robledo, T.H. Taminiau, M. Markham, D.J. Twitchen, L. Childress, and R. Hanson
Heralded entanglement between solid-state qubits separated by 3 meters
`https://arxiv.org/pdf/1212.6136.pdf`

[4] Shuang Zhao, Hans De Raedt and Kristel Michielsen
Event-by-event simulation of Einstein-Podolsky-Rosen-Bohm experiments
`https://arxiv.org/pdf/0712.3693.pdf`