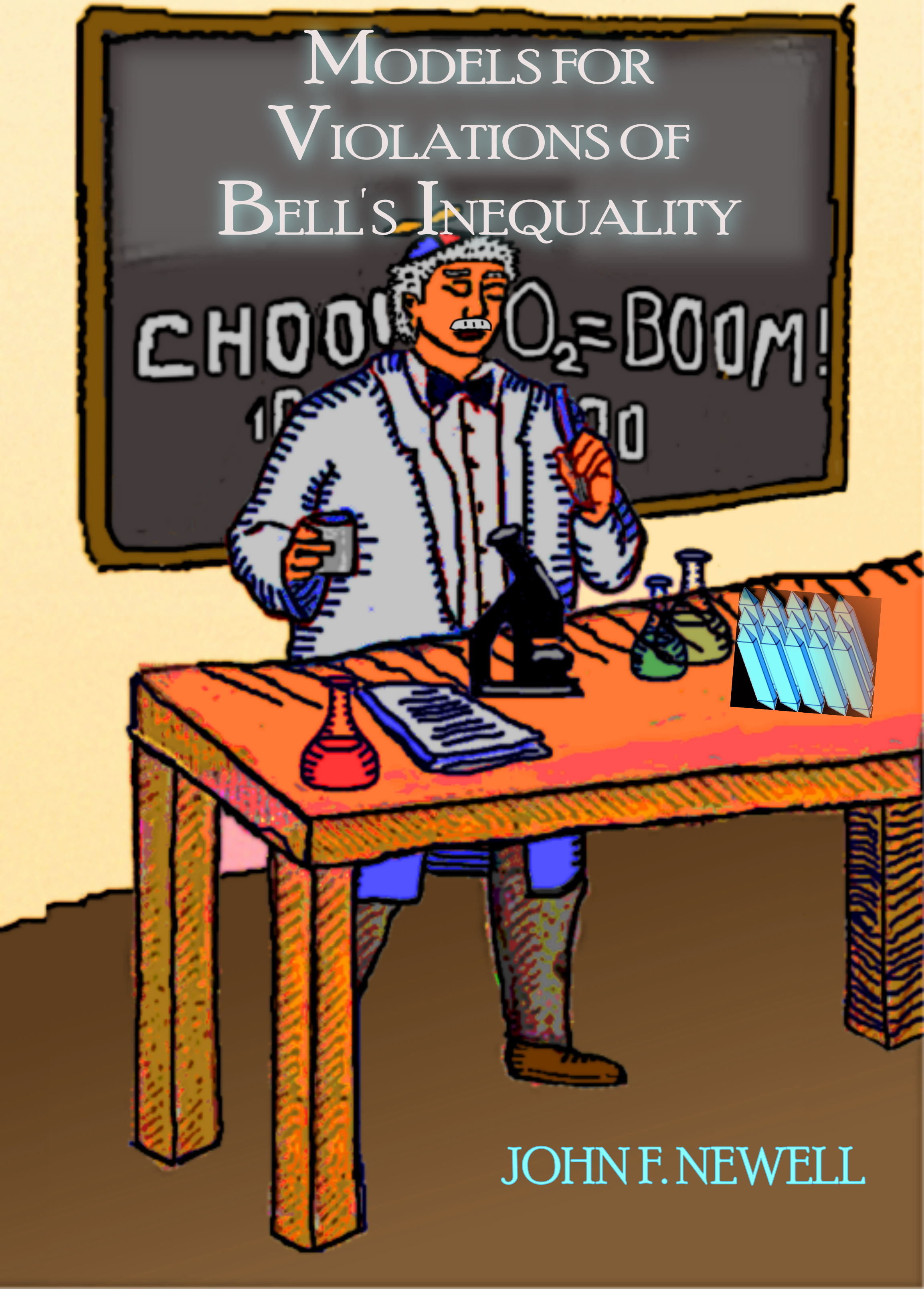
# Models for Violations of Bell's Inequality



JOHN F. NEWELL

# Models for Violations of Bell's Inequality

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## A Note to the Reader

*"Now we know how the electrons and light behave. But what can I call it? If I say they behave like particles I give the wrong impression; also if I say they behave like waves. They behave in their own inimitable way, which technically could be called a quantum mechanical way. They behave in a way that is like nothing that you have seen before. Your experience with things that you have seen before is incomplete. The behavior of things on a very tiny scale is simply different….like nothing you have seen before.*

*"The difficulty really is psychological and exists in the perpetual torment that results from your saying to yourself, "But how can it be like that?" which is a reflection of uncontrolled but utterly vain desire to see it in terms of something familiar. I will not describe it in terms of an analogy with something familiar; I will simply describe it. There was a time when the newspapers said that only twelve men understood the theory of relativity. I do not believe there ever was such a time….On the other hand, I think I can safely say that nobody understands quantum mechanics. So do not take the lecture too seriously, feeling that you really have to understand in terms of some model what I am going to describe, but just relax and enjoy it. I am going to tell you what nature behaves like. If you will simply admit that maybe she does behave like this, you will find her a delightful, entrancing thing. Do not keep saying to yourself, if you can possible avoid it, "But how can it be like that?" because you will get 'down the drain', into a blind alley from which nobody has escaped. Nobody knows how it can be like that.*

*Richard P. Feynman,*
*The Messenger Lectures, 1964, MIT*[a]

[a] Source:
http://bouman.chem.georgetown.edu/general/feynman.html

Despite it popularity, this is one of the most irresponsible things that a scientist, speaking in his official capacity as a scientist, has ever said. Essentially, Dr. Feynman is telling his students to give up the quest to understand the workings of nature, and, instead, learn to play a game which—don't ask him why—manages to produce answers which can be successfully applied to physical situations.

It would have been acceptable, if Dr. Feynman had said, "Nobody understands it yet, but perhaps one of you will figure it out" but, instead, he warned his listeners away from even trying, as if making the effort was the shortcut to madness.

The conviction that photons and electrons behave in ways that cannot be comprehended indicates a deeper conviction that the laws of nature are ultimately incomprehensible. No scientist should ever adopt such a point of view because the notion that we cannot figure out what nature is doing is not compatible with the mission of science, though it is perfectly compatible with superstitious beliefs and magic.

When Dr. Feynman found that photons and electrons were acting in ways that were not understood and which seemed magical, it was his responsibility—and the responsibility of all scientists in their larger role as natural philosophers—to call the world's attention to this problem and to make the world aware of its nuances and implications. Indeed, since magic is the antithesis of science, selfinterest—even unenlightened selfinterest—should have impelled them to try to save their own ship from sinking. Yet, where was their call for help, their S.O.S, their red alert, their call for all hands on deck?

To be sure, Einstein and some others attempted to treat the situation like the emergency it was, but their efforts were dismissed as an effort to hold on to an old-fashioned way of thinking. The loudest voices advocated a kind of unthinking acceptance; while scientists in most other disciplines 'bravely' ducked the issue by retreating to their areas of specialization, pretending that it wasn't their problem. A few physicists, perversely, even took some pleasure in seeing the waters well around their ankles.

When Feynman said that nobody understands quantum physics and discouraged his students from even attempting to do so, [b] there should have been a storm of outrage; instead, everybody had a good laugh and lined up to join the lunacy parade. His line became a slogan, and, as a consequence, many took newfound pride in their ignorance. "We don't know what we're doing, but we sure as hell are successful at doing it," sums up the slap-happy attitude which came to dominate most of those who knew about the problem.

True philosophers do not have the luxury of ducking difficult questions. It is not an option, for them, to unthinkingly accept the outcomes of some mysterious process and call it knowledge. And it is not acceptable for them to be frightened away from some area of inquiry.

Consequently, contrary to Dr. Feynman's advice, we are going to take a short stroll down that "blind alley from which no one has ever escaped," and to learn a way to answer that nagging question, "But how can it be like that?" in terms of something familiar. I think you will find

[b] For more commentary on this quotation, see: http://www.hellos.com/physics/feynmancommentary.html

that the alley is nothing like a dark and scary place, and that it's not even a confusing place.

In order to get started, let's take a look at how the situation developed.

**Some Historical Background**

In the early 1930s, Einstein and some colleagues noticed something potentially peculiar. Looking at the equations arising from quantum mechanics, it looked as if, under certain circumstances, something done on this side of the world would have an instantaneous effect on something happening on the other side of the world. This was a problem because Einstein's theory of relativity dictated that physical causes could not move faster than the speed of light, so an instantaneous effect looked an awful lot like magic.[c] Einstein called it "Spooky action-at-a-distance."

The next stage occurred about 30 years later when John Bell compared the predictions arising from the equations of quantum mechanics to the outcomes permitted by probability theory. What he found was that the outcomes which quantum mechanics was calling for could not be reconciled with what probability theory allowed. At this point we did not have a mere hunch or conjecture (as we had with Einstein's observation) but solid, mathematical *proof* that there had to be some kind of instantaneous cause at work *if* what quantum mechanics predicted was true.

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[c]Even if one is not totally enamored with Einstein's speed limit, it does make sense to maintain that mechanical causes should take some time to propagate.

This last qualification paved the way for the next stage, because it raised the question, “Are the predictions of quantum mechanics true or not?” This was a matter for experimentation, and, although it took fifteen years to get all the kinks ironed out, eventually the results were in: the predictions of quantum mechanics were correct.

### The Immediate Implications

The consequence of this can be phrased in different ways, here are a two:

1. Magical interactions—instantaneous, nonphysical influences on distant objects–are a mathematically and scientifically established reality.

2. The theory of relativity does not apply to quantum objects, although it does apply to things composed of sufficiently many quantum objects.

The second option, or something like it, was the one embraced by most physicists, but the tale of Schrödinger’s cat made it clear that the effects of quantum interactions could easily be transferred to non-quantum objects, so the differences between these two approaches fade rather rapidly, and the second takes on the appearance of an attempt to sweep the first under the rug.

Yet, why should the first interpretation be covered up? What is wrong with living in a magical world?

There may not be anything wrong with living in a magical world, but it is hard to be a *scientist* in such a world. Becoming a scientist involves rejecting the notion that things happen magically, and substituting the idea that things happen mechanically. The true scientist searches for physical causes for perceived effects, and when he does not find them, he looks harder.

For at least the past 500 years, not only have the scientists consistently prided themselves on finding mechanical explanations for what others had assumed was magic, but they have also managed to do, mechanically, many things which those who put their faith in magic could only dream of doing. Over the years, the scientists had graduated from striving against the magicians, to laughing at them, and then to treating them dismissively—they were no competition; they were just dreamers.

By 1930, the scientists had come up with a mechanical system, quantum mechanics, which provided amazingly accurate predictions for any experiment they could dream up. The quest of science was nearing its end. And then, what did they find deep in the heart of it? Magic.

As noted above, many were happy to accept this out come, but for the next 50 years the most responsible scientists kept trying to find ways to get rid of that magic. The case for its presence, however, kept getting stronger. In the end, they gave up the fight and accepted it as a reality.

But that's not to say that they were happy with that fact, or even comfortable with it, for who is ever comfortable with the discovery that they must now accept what they have been mocking others for thinking?

This, then, can account for the silence of a fair number of the scientists in light of this discovery, but what can account for their capitulation on their fundamental principle that the world functions mechanically and not magically? Did we not say that a true scientist looks for physical causes, and, when he does not find them, he looks harder? Where in that sentence does it say that he eventually gives up?

Yet, as Feynman's quote above makes clear, they did give up, and the best explanation for why they did it is this: they didn't know any better; nobody had told them that quitting was not an option. When Feynman, the leading mind in the field, actively encouraged his students and colleagues not to seek a solution, they dutifully did what they were told, even though that meant undermining more than 500 years of scientific effort.

We could place the blame for this on Feynman because we can convict him with his own words, but the intellectual environment in which he spoke those words did not find them shocking or subversive. By the time he spoke out, the damage had been done for a long time, and he merely said, in a catchy and memorable way, what everyone else was already thinking.[d]

The blame, then, must be placed on the educational system which allowed the idea that quitting was an option to take root and grow. But how did that happen?

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[d]The fact, indicated by Feynman, that the newspapers were eager to report that only 12 men understood the theory of relativity is an indicator of the spirit of the times: the newspaper and their readers wanted to believe that scientists could discover something so 'deep' that nobody could understand it. People in more sensible times view 'explanations' that don't make any sense not as truth but as nonsense.

## Some More Historical Background

Sometime in the 1800s if not earlier,[e] a sufficient number of influential scientists ceased to think of their discipline as a form of natural philosophy—a search for the truth about nature and how it operates—and started to think of it as a mathematical and physical quest for finding ways to get things done. In a very real sense, what nature was actually doing ceased to be a matter of interest to scientists; instead, all they needed were mathematical formulas, provided those formulas produced results that mapped onto experimental outcomes.

For many, this may appear to be a very subtle distinction, but it makes a big difference. These days, we scoff at the ancient Greeks who thought that the earth was at the center of the universe. Their conception of things had nothing to do with the way things actually are in nature, and we regard them as foolish for thinking that it did. What is odd, however, is that their wrong-headed hypothesis produced mathematical models which did work and still do work[f] amazingly well at predicting where a given planet will appear in the night sky at a given time. Their theoretical system is totally divorced from reality, and yet it can produce reliable, usable results!

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[e] Isaac Newton actually set the precedent for this when he intro duced the notion of gravity, and provided all kinds of mathematics to explain how it worked, but then, in his "General Scholium" confessed that he didn't have any idea of what gravity was.

[f] Some discrepancies can arise, but these can easily be corrected by tweaking the system so that it accommodates motions and heavenly bodies discovered since the time of Ptolemy.

The moral of that story is that it is possible to come up with all kinds of crazy ideas, couple them with mathematics, and produce formulas which will accurately predict the outcomes of scientific experiments. Consequently, if our focus is only on producing and testing such formulas, we could end up learning very little about nature. When science shifted into the mode of producing and testing mathematical formulas, it broke free of natural philosophy and set itself on a course to marry up with those who believed in magic, even though it intended to head in the opposite direction.

But why had it made that switch? Why would scientists ever turn their back on trying to figure out what nature was actually doing?

It might be easy to make the case that the switch resulted from either a single grand conspiracy, or a combination of lesser conspiracies involving elements such as the anti-rationalist sentiments of the Romantic movement, the anti-intellectualism of the communists, the popularity (especially amongst the influential upper classes) of spiritualism and occult movements, and the desire by those who had wealth and power to preserve it by preventing access to power through knowledge,[g] but most readers will find it more plausible to conclude that it arose naturally out of an innocent, but overzealous, quest for efficiency.[h]

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[g] The equivalence of human knowledge and power was first made by Thomas Hobbes in 1651 in his *Leviathan* (1.10), which was one of the first texts intended to systematically lead the modern mind astray.

[h] The idea that too much efficiency can be a bad thing is altogether foreign to most contemporary undertakings, especially in business, the military, and most of the sciences, but

Given the increasingly competitive environment in industrial and military technology through the 19th and 20th centuries, it became important for companies and governments to produce technological improvements rapidly, and this might best be achieved by having as many minds as possible working on any given problem. In order to get those minds, people had to be educated, and it was discovered that a good number of people could catch on quickly if they were taught little more than how to apply and manipulate a list of mathematical formulas. With this approach, it did not matter if a student could say 1) what electricity, or magnetism, or electrons, or other physical entities were, or 2) why they existed, or 3) why they behaved according to the known sets of rules and not some other set, so long as they could apply the appropriate set of formulas to any given problem and successfully work out the math. While this sort of education turned out to be either confusing or of little interest to students with ‘deeper' philosophical concerns, it suited the practical interests of the primary sources of educational funding (industry and government) because it turned out capable students in quantities sufficient to provide them with the desired out comes, and so the funders and their schools chose to forgo

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too much of anything is a bad thing and biology can provide an abundance of examples which prove that unrestrained efficiency is the road to extinction: if an animal is too good at hunting its prey, or too efficient in reproducing, or too successful at eluding predators (as are, for example, invasive species), there will eventually be too many members of that species and no food for them to eat.

whatever advantages ‘deeper’ forms of education might eventually produce in a few, select minds. [i]

Although such a system clearly fosters a dangerous shallowness of mind, the benefits of this approach are abundantly visible in the world today. In some countries, the standard of living–even amongst their middle classes–rivals or exceeds that of the ancient gods of Olympus. We can congratulate ourselves for having found the shortcut to the top of the hill, and some might say it was a good thing that we divorced philosophy and science when we did, and a shame that we didn’t think of doing it sooner. By liberating ourselves from those ‘deeper’ concerns which were bogging us down, we’ve reaped a greater reward than we could have dreamed of at the start. So there’s your proof: all’s well that ends well.

**The Danger At Hand**

The wise—those killjoys who often see trouble brewing while others are dancing in the streets—might view this approach as flawed despite its success. What is the price that we will pay (or have already begun to pay) for advancing know-how at the expense of understanding? What are the consequences of having so many people in the world who think they know everything, when, in fact, they know

[i] It should be remarked, with emphasis, that this does not mean that none of those taught to merely manipulate formulas had deeper insights into what they were doing, students were welcome to think as deeply as they wished, but such concerns involved matters which were outside the curriculum, and, when they became employed, outside their job description. Philosophy and science had parted ways.

very little indeed? What is the consequence of having raised 'intellectuals' who are not only comfortable with, but staunch advocates of ideas which cannot stand up to even the simplest kind of philosophic scrutiny? What will happen when these deluded people apply their 'learning' to raising their children, feeding their families, running companies, governing citizens, or to using the atomic bomb?

These are not idle questions. The consequence of the policies and funding decisions of the past 150 years have produced a situation in which wealth and power are increasingly concentrated, not in the hands of the wise, but in the hands of these ill-educated manipulators of formulae. They are beginning to run the world, and will probably continue to do so until there is no world left to run.

Why is this likely to be the case? Because theirs is the more efficient system; because, while they have no real sense of the bigger picture, they have know-how and, increasingly, money and power on their side. Very little happens in the world when these three are not combined.

Why is this dangerous? Since at least the time of Thales (about 600 BC), a leading principle of the Western intellectual tradition had been that the universe was organized on rational principles and that the human mind could discover the universe's underlying rational order. Natural philosophy was the product of applying those beliefs to the physical world, but the belief in a rationally ordered universe also bolstered the Western sense of justice, and fostered ideas such as that laws should be reasonable. Certainly, there were those who disagreed or despaired along the way, but no one could *prove* that these beliefs were misguided. When, however, the scientists conceded that there was mathematical proof corroborated with physical evidence that established, as a matter of irrefutable scientific fact, that the universe did not act in accordance with rational principles, the supports were kicked out from beneath this system of beliefs. Consequently, while our own cultural momentum has kept us operating as if it is right to expect reasonable treatment from our governments, our employers, and our neighbors, science had shown that there is no sound basis for such expectations. Fortunately, either few people realized what had happened or few dared to act on it, and so law and order have thus far been preserved.

**Is There Hope For The Future?**

This book argues that the scientists drew their conclusions too hastily, and so it aims to restore the foundation for everyone's expectation of reasonable treatment, but this could end up being a case of 'too little too late,' for what is this book but a lone voice trying 1) to counter a tradition in scientific education that has been established for over 100 years, and 2) to overturn mystical notions of spooky action-at-a-distance which scientists have grown comfortable with over the past 80 years?

It will not be easy to revoke the license that the scientists have granted to those who wish to live without regard for the constraints of reason. Additionally, it may not be easy to convince the scientists that they have gotten onto the wrong path, for they may also choose either not to be reasonable, or to simply ignore what is said here.

The best response to this situation arises through education, but not education in the 'career preparation' sense of the term (which is an outgrowth of the same forces which separated science from philosophy) but education in the older, fuller sense, which focuses on fostering a desire for discovering the truth in students, and giving them the intellectual skills required to let them seek and discover truths for themselves.

And the case is not hopeless. In saying that the scientists have been poorly educated, we admit not only that they are educated (albeit partially), but also that they are educable. In addition, we have already remarked (see note i above) that some of them have learned more than their educations sought to teach them. We can add to this that many of these scientists have not been fooled by their educations. They are smart enough to know that the education they have been given is the equivalent of junk food for thought, and are eager to learn more. Such scientists are already natural philosophers at heart. All that is necessary, then, is to show them that there is a substantive alternative to the education they've received.

The contents of this small book are offered as a place to start. They offer an alternative way to look at the magical or 'spooky action-at-a-distance' interaction we discussed above. This book does not introduce any new material to quantum mechanics or alter how it functions in any way. Instead, it quickly reviews a new area that's been discovered in probability theory, and then shows how to construct a model for the process of polarizing light. The patch, together with the model, can be employed to exactly duplicate the outcomes which got everybody so baffled about quantum mechanics.

As a result, people now have a choice. They can stick to the old 'we don't know what's going on or what we are doing, but we get results' approach, or they can graduate to this model and investigate it until every aspect of the interaction becomes clear to them. That is to say, this book puts them in position to freely choose whether they'd like to remain a 'the world doesn't make sense but we can manipulate the formulae' scientist (the sort Feynman exhorts them to be in the quote given above), or if they'd prefer to be an 'I understand the world' natural philosopher.

In order to remove any financial obstacle that might impede one from making an informed choice in the matter, I am giving electronic copies of this book to one and all, free of charge.[j] If you enjoy the book (or at least learn something from it) please join me in this effort to change the course we are on and pass this book on to others. If the book evokes some kind of negative response from you, please repay the author's generosity by having the decency of expressing your thoughts in writing to the author directly and privately. [k] If you would like to enrich your mind in other, related ways, you may consider the texts advertised at the end.

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# Modeling Violations of Bell's Inequality

John F. Newell, PhD
Fall 2014

## Introduction

In 1935, Einstein, Podolsky and Rosen (EPR) published an article[a] which questioned the completeness of quantum mechanics. They were troubled because the mathematics of quantum mechanics suggested that the outcomes of certain, distantly separated experiments should oddly turn out to be identical. In 1964, John Bell[b] showed that the correlation rate which quantum mechanics predicted for such experiments would exceed the bounds permitted by probability theory. Experimentalists then modified Bell's proposed experiment (which created a class of experiments which came to be known as Bell tests), and developed variants of his argument (which created a class of proofs, often referred to as 'Bell's Theorem' or 'Bell's Inequality') in various attempts to determine whether quanta obeyed the constraints of probability or the dictates of quantum mechanics. Starting in 1981, Alain Aspect[c] conducted definitive experiments showing 1) that photons did, in fact, violate the constraints of probability theory, 2) that they did so to just the degree that quantum mechanics predicted, and 3) that they could do so even under conditions which, according to the theory of relativity, did not permit any causal link between them to function. It appeared, then, that photons at least (and perhaps nature in general) regularly engaged in what Einstein once called "Spooky action at a distance."[d] In 2014, however, Newell[e] showed that the problem arose from an incompleteness in probability theory. He did this by introducing probabilities related to directional similarity. These new probabilities matched those which arose from quantum mechanics, and so served to significantly reduce the worry that nature regularly engages in magical practices. Newell's article, however, only provided a mathematical argument for expanding probability theory, and stopped short of showing how the results from EPR or Bell tests could come about from a mechanical point of view. The purpose of this small book is to describe a set of mechanical processes which can serve, on the level of models or analogies, to show how these events occur.

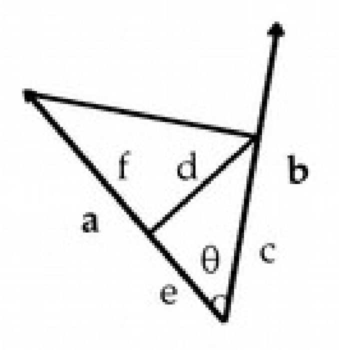


**Figure 1:** Vectors **a** and **b** meet to form angle θ Projecting **a** onto **b**, we get *c*; projecting *c* onto **a**, we get segments *f* and *e*; *e* shows the degree of similarity between **a** and **b**, while *f* shows the degree of dissimilarity.

## 1. Probabilities Related to Directional Similarity

Newell's article introduces probabilities related to directional similarity and makes a case that these underlie the experimentally confirmed correlations predicted by quantum mechanics. Essentially, the method is introduced by discussing the acute angle $\theta$, the degree of relative rotation between the compared orientations (**a** and **b**) of the detectors, and then resolving **a** into orthogonal components such that one component lies along **b**. The component in the direction of **b** is then projected back onto **a**. The segment, *e,* cut off along **a**, maps the component onto the vector, thereby revealing the component's influence on the vector. Consequently, *e* can be used to produce probabilities (see figure 1). Trigonometry reveals that:

$$e = cos^2\theta. \qquad [1]$$

This equation is then further generalized as:

$$e = \frac{\|\mathbf{a}\|\, s}{\|\mathbf{b}\|\, t} \cos^2 \frac{\pi}{2\xi}(\theta) \qquad [2]$$

Where $\|\mathbf{b}\| \geq \|\mathbf{a}\|$ (in order to keep *e* in the range between 0 and 1; *s/t* is any part to whole ratio which has bearing on the sample being studied,[1] and $\xi$ is related to the wavelength,[2] $\lambda$, such that, for a symmetrical curve like that of $cos^2\theta$, $\xi$ is the portion of the wavelength (measured in radians) which extends from 1 to 0 (or 0 to 1)—essentially the term $\pi/2\xi$ scales $\pi/2$ (or 90 degrees) to this portion of the wavelength. The purpose of this is also to keep the value of

1 The examples furnished below will help clarify the role of *s/t.*
2 That is, $\xi$ is a portion of the wavelength when dealing with a static picture of the wave (that is, for example, the *y* displacement at different coordinates for *x*). When dealing with a wave in motion (for example, the *y* displacement as time changes), $\xi$ would be a portion of the period.

*e* between 0 and 1. Equation [1] results when $||\mathbf{b}|| = ||\mathbf{a}||$, $s = t$ and $\xi = \pi/2$.

## 1.1 Application to Equations from Quantum Mechanics

We are interested in Bell-type experiments (such as the CHSH Bell test[f] or the CH[g] test[3]) which involve comparing the output from distant polarizers (*P* and *Q*) which have been rotated relative to one another. Since the output is polarized light, and that may take two forms, *C* and *U* (one orthogonal to the other), the circumstance allows for four output sets:

| | **P** | **Q** |
|---|---|---|
| 1 | C | C |
| 2 | C | U |
| 3 | U | C |
| 4 | U | U |

**Table 1:** Four possible correlation combinations for *U* or *C* outcomes at *P* and *Q*.

Sets 1 and 4 contain matching members and so may be labeled 'matches'; sets 2 and 3 do not match, and so may be labeled 'mismatches'. There are two kinds of matches $(P_C,Q_C)$ and $(P_U,Q_U)$, and two kinds of mismatches $(P_C,Q_U)$ and $(P_U,Q_C)$. If we are interested in one of the two matching sets, say, the match $(P_U,Q_U)$, then the term *s/t* in equation [2] becomes *1/2*. If we are interested in a mismatched set, we must look to the influence of the orthogonal component and so substitute *f* for *e* and *sine* for *cosine* in equation [2]. If we set $\xi = \pi$, then we can write $cos^2(\theta/2)$ for the final

3 The CHSH test was devised by Clauser, Horne, Shimony and Holt in a paper[f] published in 1969; the CH text was devised by Clauser and Horne in 1971.[g]

term. From this we can construct the following table of equations:

| Target Outcome Set | CHSH Test | CH Test | Equation Reference Number |
|---|---|---|---|
| Both $(P_C,Q_C)$ and $(P_U,Q_U)$ | $\rho = cos^2\theta$. | $\rho = cos^2(\theta/2)$. | [3] |
| Only $(P_C,Q_C)$ or $(P_U,Q_U)$ | $\rho = ½cos^2\theta$. | $\rho = ½cos^2(\theta/2)$ | [4] |
| Both $(P_C,Q_U)$ and $(P_U,Q_C)$. | $\rho = sin^2\theta$. | $\rho = sin^2(\theta/2)$. | [5] |
| Only $(P_C,Q_U)$ or $(P_U,Q_C)$. | $\rho = ½sin^2\theta$. | $\rho = ½sin^2(\theta/2)$. | [6] |

**Table 2:** Equations for degree of similarity of outcome for CHSH and CH Bell tests

In table 2, ρ has been substituted for *e* because, in the discussion related to equation (1), *e* reflected the degree of similarity, but here we need a term which encompasses both similarity (equations [3] and [4]) and difference (equations [5] and [6] where *f* would play the role of *e*).

For the CHSH test, matches are assigned a value of +1 and mismatches a value of -1, consequently, the expectation value, *E*, becomes:

$$E = cos^2\theta - sin^2\theta = cos2\theta \qquad [7]$$

Running the test four times, with θ set three times to 22.5°, and once to 67.5°, and summing the expectation values for each test, we find:

$$S = 3(\cos[45^o]) + \cos(135^o) = 2.83 \qquad [8]$$

This is the same value (and the same equations) which quantum mechanics says will govern the outcome of these tests. Bell's hypothesis, reached without an awareness of directional similarity, asserted that probability theory restricted $S$, such that $|S| \geq 2$. Experiments, however, have confirmed the value found in equation [8].

For the CH inequality, we work towards an absurdity by beginning with an algebraic consideration, namely that, numbers $x_1$, $x_2$, $y_1$, and $y_2$ can serve as probabilities if they each have values, $v$, such that $0 \leq v \leq 1$.

Given such values, the function $S = x_1y_1 - x_1y_2 + x_2y_1 + x_2y_2 - x_2 - y_1$ is constrained by the inequality $-1 \leq S \leq 0$ because:

- S = 0 when all $v = 0$,
- S = -1 when all $v = 1$
- In other cases, multiplication renders $x_1y_1$, $x_1y_2$, $x_2y_1$, and $x_2y_2$ equal to or smaller than their individual values $v$, and subtracting $x_1y_2$ renders the sum of the others even smaller. Subtracting both $x_2$ and $y_1$ from this diminished sum pushes the total below 0.

Setting:

$$x_1 = \mathrm{p}(Pa) \qquad [9]$$

$$x_2 = \mathrm{p}(Pa') \qquad [10]$$

$$y_1 = \mathrm{p}(Qb), \qquad [11]$$

$$\text{and } y_2 = \mathrm{p}(Qb'), \qquad [12]$$

where

p($Pa$) is the probability of getting a positive readout on $P$ when $P$ is in position $a$;

p(*Pa′*) is the probability of getting a positive readout on *P* when *P* is in position *a′*,
p(*Qb*) is the probability of getting a positive readout on *P* when P is in position *b*
and p(*Qb′*) is the probability of getting a positive readout on *P* when *P* is in position *b′*.

Then

$$-1 \leq p(Pa,Qb) - p(Pa,Qb') + p(Pa',Qb) + p(Pa',Qb') - p(Pa') - p(Qb) \leq 0, \qquad [13]$$

where *Pa,Qb*, *Pa,Qb′*, *Pa′,Qb* and *Pa′,Qb′* are all some kind of matching output. If we set the positions *a*, *a′*, *b* and *b′* such that the relative rotations have the values:

$$ab = 0°$$
$$ab' = 120°$$
$$a'b = 120°$$
$$a'b' = 240°$$

we find that, using either directional similarity (the equations in table 2) or the formulas provided by quantum mechanics (which are identical to the equations in table 2), the probabilities have the values:

$$p(Pa,Qb) = ½cos^2(0°) = 1$$
$$p(Pa,Qb')) = ½cos^2(60°) = .25$$
$$p(Pa',Qb) = ½cos^2(60°) = .25 \text{ and}$$
$$p(Pa',Qb') = ½cos^2(120°) = .25,$$

while p(*Pa′*) = p(*Qb*) = 0.5 (since the outcomes can either be positive or negative, and there is no bias one way or the other). This would yield, for equation [13] above:

$$-1 \leq 1 - 0.25 + 0.25 + 0.25 - 0.5 - 0.5 \leq 0.$$

This reduces to:

$$-1 \leq 0.25 \leq 0, \qquad [14]$$

which is obviously false.

This result tells us that the probabilities supplied in table 2 do not arise by multiplying together the probabilities given in equations [9] - [12]. In other words, the correlation rate appears to be independent of the joint probabilities, which are governed by the probability of a given outcome at a given detector.

Before the discovery of probabilities based on directional similarity, the absurdity of equation [14] was proof enough that quantum mechanics stood at odds with probability theory, now, however, this outcome simply serves to indicate that the probabilities of directional similarity form a distinct branch within probability theory, and that the equations yielded by quantum mechanics arise from within this 'new' branch. The independence of directional similarity from joint probabilities can be understood in this way: joint probabilities arise from combining independent probabilities, while probabilities involving directional similarity do not; directional similarity is a relational situation, so there is no independent state from which they may arise. For example, we cannot say a man is fatter or thinner, taller or shorter, faster or slower, and so forth until we have another person (which could include him at another time) to compare him to: the relation springs into being when there are two to compare. Similarly, then, we cannot assign a degree of directional similarity when we have nothing but a single oriented item (such as a single detector)—until a relation is established, the degree of directional similarity is undefined, just as you cannot have a Euclidean angle if you are given nothing but a single straight line.

In both the case of the CHSH-Bell inequality and that of the CH-Bell inequality, we have seen that the equations arising from directional similarity match those which arise from quantum mechanics, and stand at odds with the dictates of traditional probability theory. The advantage that directional similarity introduces is that it provides an *understandable*, geometrically-based, mathematical account of where these probabilities come from, whereas quantum mechanics simply supplies them as formulas and provides no insight into their origin or comment as to why they work. Since, in fact, the situations to which these equations apply involve rotational orientations of detection equipment, it is entirely reasonable to assert that the probabilities arising as formulas in quantum mechanics are, in fact, probabilities involving directional similarity—that is, the fact that the equations arising in quantum mechanics are identical to those of directional similarity is not a coincidence, but the result of the fact that two different roads have led to the same destination. Consequently, we may now use directional similarity as a means for explaining quantum events.

## 2. Modeling Polarization

In order to model the process of polarization, we must develop models for both photons and polarizers. The process is not simple, because photons are conceived as both particles and waves, and polarizers occur as both absorptive polarizers and birefringent polarizers. We will have to develop models which cover all of these possibilities. We can begin by modeling photons.

### 2.1 Corpuscular Photons

The problem of polarization has colored the way that photons have been conceived, but, because polarization has not been well understood, the result has been a rather peculiar conception of the photon. This description seeks to free the photon of some of those peculiarities. We will begin with a description of corpuscular photons, and later make some comments about photons as waves.

Like all physical bodies, we will assign to photons both size and shape. We shall not, however, maintain that the sizes and shapes of photons are fixed. Instead, we will posit that photons are inelastic, plastic or malleable bodies, like lumps of clay or softened wax, or mashed potatoes, all of which retain whatever shape resulted from their most recent encounter with another material body. While photons are malleable, they are not infinitely compressible.[4] When photons impact an impervious physical body, they deform and compress until they reach a state of maximal compression (reached when the compressed cross-section reaches a minimal width, *r*), at that moment, they become sufficiently rigid bodies and so rebound from that body with an altered shape (i.e., the shape resulting from the impact).[5] Photons may[6] also spin about an axis. The axis of spin can be oriented in any direction, and the direction of spin can be either clockwise or counter-clockwise about that axis (viewing the photon with one's eye in line with the spin axis).

4 There are physical and philosophic reasons for this, and these reasons constitute one of the principle differences between physical objects and mathematical objects (a difference which seems to be ignored all too often in the development of mathematical physics).

5 Automobiles built in the twentieth century can furnish a handy example of this sort of physical body: in collisions, they first crumple and dent (because they are essentially a hollow cavity, covered with a metallic shell), and then, when further compression requires too much energy, they rebound from the object they have collided with. Impacts effect velocity as well, but that's a matter for another day.

6 We will discuss cases of non-spinning photons below but the world would be an oddly, highly ordered thing if any class of physical bodies never exhibited spin. For the purposes of this discussion, the rate of rotation must be high compared to the velocity of the photon.

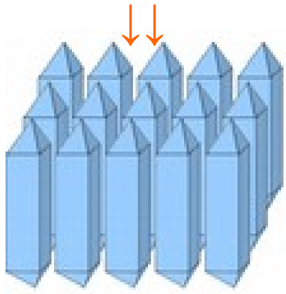

**Figure 2**: Orthogonal array modeling a polarizer.
Arrow shows direction of incoming photon stream

In a Bell-type test (such as the CHSH test), pairs of photons with identical or duplicated properties are passed through a polarizer. For our purposes, the physical features necessary to explain the outcome will be 1) that the spin axes of the paired photons are parallel, and 2) that the photons are similar in shape (they share, at least, a minimal width, *d,* measured in at least one plane perpendicular to the axis of rotation)

## 2.2 Birefringent Polarizers

Birefringent polarizers divide an incoming beam of light into two beams, one which proceeds more or less straight through the polarizer (the ordinary ray) and one which is deflected to a noticeable degree (the extraordinary ray). The two rays differ not only in their paths of emission, but in their direction of polarization: one is polarized orthogonally to the other (for example, if the ordinary ray is polarized horizontally, then the extraordinary ray is polarized vertically). In order to model this, we can begin with an array of cuboids, each capped, top and bottom, with a square-based pyramid so that they resemble the crystals one finds on certain chandeliers (see figure 2).

If we set the distance between the parallel sides of the adjacent 'crystals', $D$, such that $r \leq D \leq d$, then this model provides two sets of channels for photons to pass through the polarizer, one set consists of channels parallel to the *xy* plane, the other consists of channels parallel to the *yz* plane. Two consequences arise from the fact that the channels are narrower than the photons, first, the photons must deform in order to pass through them (it may be desirable that $D \leq \frac{1}{2}d$, provided that $r < \frac{1}{2}d$), and second, the photon's spin will be stopped due to drag produced from contact with the walls of the channel.[7]

In order to model the deflection evident between the ordinary and extraordinary rays, we must shear the array shown in figure 2, resulting in the array shown in figure 3. With this arrangement, photons passing though the channels parallel to the *xy* plane will pass straight through the polarizer, and will be reshaped into discs parallel to the *xy* plane. Since these photons pass directly through the polarizer without deflection, they constitute the ordinary ray, and we can call the channel though which they passed the 'ordinary channel'. Photons passing through the other channel (let us call it the 'extraordinary channel' because the photons which pass through it constitute the extraordinary ray) will emerge on a path which is parallel to a plane that is oblique to the *xz* plane, and they will be shaped as discs parallel to that plane. This obliquity will not prevent these discs from being perpendicular to those emerging through the ordinary channels, so the orthogonal polarization of the two emerging rays is not disrupted by the shear.

The degree of sheering of the extraordinary channels must be great enough that the tops of the crystals align over the bases of the adjoining crystal (this will prevent cross-over

7 These considerations make it clear that photons are sizeable, and so, most likely, waves.

emissions from the extraordinary into the ordinary ray, or *vice versa*), but not so great as to allow the sides of the capping pyramids to be perpendicular to the path of the incoming photons (this will prevent the photons from being reflected off the surface of the polarizer). It should be possible to arrive at more precise specifications for the polarizer by building such an array and observing the consequences of making various adjustments.

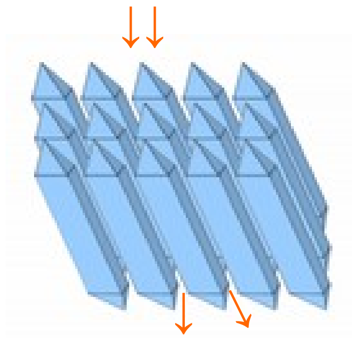

**Figure 3**: Arrows show incoming photon stream (above) and paths for exiting or-dinary and extraordinary rays (below).

## 2.3 Birefringent Polarization

With these models for the photon and the birefringent polarizer, we may now describe how polarization occurs when they interact. The incoming photons are each unique in terms of their shape, the orientation of their axis of spin, and the direction of their spin about that axis. On impacting the array which constitutes the birefringent polarizer, the photon's spin causes it to roll along the inclined face of the pyramidal cap(s) it strikes on impact. This roll will direct the photon into either an ordinary channel or to an extraordinary channel (except in the rare case when a photon lands on the edge of one of the pyramidal caps and the photon's axis of rotation is aligned so as to be exactly perpendicular to that edge, with the result that the photon rolls down the edge and into an intersection within the array[8]). Because the channel into which the photon is directed is determined by the direction of the photon's axis of spin, it is not entirely a matter of chance as to which path the photon later emerges on, however, since the axes of rotation in a stream of photons are randomly rotated, the output stream takes on the *appearance* of having resulted from a random process because the path that one photon takes in no way influences the path which the preceding—or the next, or any other—photon ends up taking.

In cases in which the photon's spin axis is parallel to one of the channels, its spin will roll it either directly towards that channel or in precisely the opposite direction. If it rolls towards the channel, it will enter the channel, and its spin will be stopped by contact with the walls of the channel, but its forward progress will continue. If it rolls away from the channel, either its forward motion (at no less than the speed of light) will insure that it enters the channel anyway, or it will enter the parallel channel on the other side of the impacted pyramidal cap, or perhaps it will be slowed or stopped, and then knocked about by successive photons. At any rate, its spin will not cause it to roll towards a perpendicular channel.

In cases in which the photon's axis of rotation is perpendicular to the channel to which the pyramidal face the photon has impacted is inclined, the rotation will cause the photon to roll towards one of the perpendicular channels on either side of that pyramidal face.

8 In such rare cases, the photon will eventually be jostled into one channel or the other. Only in such cases is the channel which the photon ends up in a matter of random chance.

In general, the direction of roll will be perpendicular to the orientation of the photon's spin axis. To visualize this, let us represent the pyramidal cap of one of the crystal cells of the polarizer as a flattened square with the diagonals representing the edges of the pyramid (as in Figure 4), and let us fix the center of a pointer or needle to the point where the diagonals cross, so that it may rotate freely parallel to the square. We may now rotate the needle so that it is parallel to the spin axis of any given photon.[9]

Consequently, if, for a given photon, the needle ends up aligned so that its ends lie within areas *a* and *b*, the photon will roll towards channel *A* or *B*, and, if its ends lie within areas *c* and *d*, the photon will roll towards channel *C* or *D*. Since *A* and *B* are parallel, all photons whose spin axis can be represented by a needle pointing into areas *a* and *b*, will end up polarized in the same direction and exit along the same path (say, that of the ordinary ray). Similarly, then, all photons whose spin axis can be represented by a needle pointing into areas *c* and *d*, will end up on the path of the

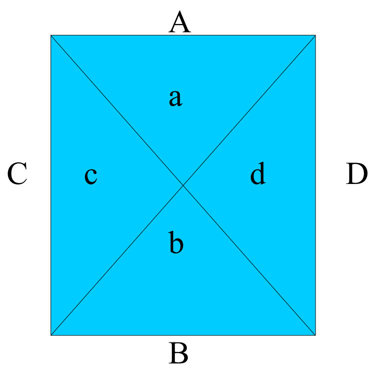


**Figure 4:** Schematic 'top view' of polarizer's pyramidal cap showing sides a, b, c and d, and channels A, B, C and D.

9 Or (to include cases where the axis does not lie in a parallel plane.) whose projection of their spin axis onto the plane of Figure 4 is so oriented.

extraordinary ray (via channels *C* and *D* or those parallel to them), and will be polarized perpendicularly to those emitted along the ordinary ray.

From this consideration, we can see that even a slight variation in the orientation of a photon's spin axis could make the difference between its ending up in the ordinary ray or the extraordinary ray. Correspondingly, if we were to rotate the polarizer even slightly, it would make a corresponding difference in the outcome state for a fair number of photons.

Consequently, if we take two photons with parallel spin axes, and send one to one polarizer, *P*, and send the other to polarizer *Q* which is aligned so as to be parallel with *P*, then the outcomes at *P* and *Q* will inevitably match: the photons will, each, emerge in the ordinary ray emitted from their respective polarizers, or they will both emerge in their extraordinary rays. This is the "spooky action at a distance" which Einstein famously complained about.

If we take two photons with parallel spin axes and send one to *P* and the other to *Q*, but, this time, rotate[10] *Q* to some degree, the likelihood of getting matched outcomes will be diminished to an extent which varies directly with the degree of rotation—the greater[11] the rotation, the less likely it is that a match will occur. The probability of getting a match,

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10 The rotation of the polarizers is restricted because the polarizers, *P* and *Q* must remain perpendicular to the path of the incoming photon. Consequently, the rotation is restricted to clockwise or counterclockwise rotation within that perpendicular plane. The relative rotation can be found by using the initial (parallel) orientation as a reference (by drawing a line through what will be the center of rotation) and then measuring the angle through which that line is moved when the polarizer is rotated.

11 The degree of rotation is to be measured by the smallest angle between the original position and the end position.

therefore, depends on the degree of directional similarity between *P* and *Q*. This can be quantified using equation [2] (setting $||\mathbf{a}|| = ||\mathbf{b}||$ since the effective portion of the polarizers is determined by the approximately equal size of the photons).

This outcome, therefore, is determined by the photon's interaction with the pyramidal caps on the crystal cells which compose the array of the polarizer. Once the photon is directed to a channel, the narrowness of the channel reshapes the photon into a disc,[12] and contact with the 'walls' of the channel stop the photon from spinning. Photons in the ordinary channel continue through the polarizer without experiencing further changes; those in the extraordinary channel have the direction of their forward motion slightly modified due to the direction of the opening of the channel and its 'walls.' The photons then emerge from the polarizer[13] in two streams, the ordinary and extraordinary rays. The photons in the ordinary ray are all shaped like discs in a parallel plane, as are those in the extraordinary ray except that the plane to which those in the ordinary ray are parallel is orthogonal to the plane to which those in the extraordinary ray are parallel (see figure 5).

12 Because the photons are not necessarily spheres as they enter the polarizer, the term 'disc' used here should be understood rather loosely. One may think of the variety of shapes which a pancake may take as a rough guide to the range of shapes the term 'disc' is here meant to encompass. This qualification also applies to the depiction of photons in figure 4.

13 The pyramidal caps at the 'bottom' of the polarizer do not influence the outcome; they are there so that, if one were to flip the polarizer over, it would still function in the same way.

## 2.4 Absorptive Polarizers

If we make a slight adjustment, we may use the same model to depict absorptive polarizers. Absorptive polarizers emit approximately half of the photons which enter, so we may think of them as birefringent polarizers in which one set of channels, say those which lead to the production of the extraordinary ray, are blocked or otherwise prevent the passage of photons. The purpose of this description is to say something plausible and descriptive about how that blockage occurs.

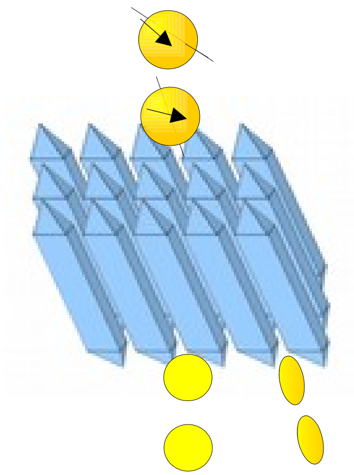

**Figure 5:** Spinning, 'spherical' photons enter at top, non-spinning, 'disc-shaped' photons emitted at bottom in two rays, the photons in one ray are orthogonal to those in the other.

It is not likely that the channels are merely blocked, for then the photons might either be reflected back the way they came, or engage in a multitude of collisions within the polarizer which should produce some measurable result, but this is not known to happen. It is more likely then, that the 'blocked' channels have an array of additional, but smaller, crystals within them. These smaller crystals serve not to sort the photons which encounter them, but to shred and deflect the photons which strike them. The photons are advancing at a tremendous velocity, and so, while they will compress if they strike a body which is broad enough or which presses on them from a direction oblique or orthogonal to their direction of travel, they can no more avoid being pierced by small or narrow objects placed directly in their line of travel than could, say, a soft apple avoid being pierced if dropped onto a bed of nails. If the nails are wedge-shaped (like cut nails), long enough, and spaced just-right, and if the apple is travelling with sufficient velocity, the impact will serve not to merely pierce the apple and slow or stop its fall, but to cause it to split into smaller pieces. If these pieces continued on to encounter a new array of nails they would be further broken and dispersed. If, then, all the parallel channels making up one of the orthogonal sets of channels in a birefringent polarizer were filled with staggered rows of small, sharp, tapered crystals,[14] the photons entering those channels would soon, due to their own softness and great velocity, be so thoroughly fragmented and dispersed that they would neither be detectable individually (due to the smallness of their size) nor as a group (due to their irregular[15]dispersal into so many different directions). Further, these fragments may disintegrate in

14 To enable the polarizer to work whether the photons enter through the 'front' or 'back', this tapering should both grow from a point to a maximum width, and recede from that width back to a point, so that it operates as a sharp wedge no matter which direction the photon is travelling within the channel.

15 That is, if the dispersal happened all at once, as from a focal point, it might be possible to detect the photon as a spherical pulse or wave radiating from that point, and if the dispersal happened in some regular fashion (e.g., symmetrically) then, while the dispersal pattern would not be a sphere, it might still be quite possible to detect it. The more irregularly the dispersal happens, the less predictable the shape of the resulting 'cloud' of dispersed fragments becomes, and so the harder it becomes to detect.

a very short time as do most subatomic particles, and that would leave nothing to detect except dispersed energy.

## 2.5 Passing Polarized Light Through a Polarizer[16]

If we take polarized light, such as that emitted in the ordinary ray by a birefringent polarizer, $P_1$, and then pass it through another such polarizer, $P_2$, the outcome will depend on the relative orientation of the two polarizers. If the two polarizers are aligned so that their 'ordinary channels' are parallel, then the photons emitted from the ordinary channel of $P_1$ will easily enter the ordinary channel of $P_2$; the only adjustment these photons may need would be a slight realignment (say a nudge to the right or the left) in cases in which the ordinary channels of the two polarizers were parallel but not in line. This nudge could be supplied by the sloping sides of the pyramidal caps on the crystals which compose the polarizer.

If, however, we rotate $P_1$ and $P_2$ relative to each other, the chances that the photon will take the same route through both polarizers (say the ordinary channel) will now depend on the degree of rotation. If the rotation is slight, there is a high chance of a correlated outcome because a small adjustment of the photon's orientation gets it through. The more the degree of rotation increases, the greater the required adjustment until, finally, the ordinary channel of $P_1$ is aligned with the extraordinary channel of $P_2$. In this final case, it would be very peculiar if the photon did not pass from the ordinary channel of $P_1$ to the extraordinary channel of $P_2$.

16 Some readers may find this section tedious. It is included in order to explain the outcomes of sequential measurements, which some have regarded as thoroughly paradoxical.

In the intermediate cases, the result is, to some degree, a matter of where and how the photon strikes $P_2$, but, since we can, on average, expect cases of one sort of extreme to be balanced by those of an opposite extreme, the case boils down to one of directional similarity. Determining θ as above in section 2.3, we can use equation [2] to calculate the odds that the photon will pass through the same channel of both polarizers (that is, that it is emitted in the ordinary ray of $P_1$, and the ordinary ray of $P_2$). If we substitute *sine* for *cosine* in equation [2] we can calculate the probability that the photon's emission path will change from the ordinary ray to the extraordinary (or *vice versa*). The *cosine* relation has long been known under the name of the law of Malus, and the *sine* relation is simply a complementary corollary.

Because the photons are plastic, their shape will readily conform to what the orientation of $P_2$ requires. When they are emitted, therefore, they seldom have the exact same shape or orientation which they had when emitted from $P_1$, (in fact, this would only occur when $P_1$ and $P_2$ are *exactly* aligned). Further, if the photon ended up in a different channel (say it went through the ordinary channel of $P_1$, but the extraordinary channel of $P_2$), then not only will it be reshaped and reoriented, but its direction of forward motion will be changed (so that, in this case, it now follows the oblique path of the extraordinary ray).

If we take these same photons, now recently emitted from $P_2$ and send them back through $P_1$, we should have a limited expectation that, on this second time through $P_1$, they should duplicate their performance from the first time through $P_1$ because, first of all, they have no memory of what they did then, and, secondly, they have been reshaped, reoriented and, in some cases, redirected in their path of travel, and, thirdly, how they fared the first time through was a consequence of their spin and the arbitrary alignment of $P_1$, but now how they fare will be a consequence of their new shape, their new orientation, their new direction of travel, and how these new properties interact with the alignment of $P_1$. The first time through, the parameters determined the outcome, the second time through, the parameters can only set a probability—indeed, as far as the photon is concerned, there is no difference between this case and the one discussed in the previous paragraph[17]—a probability set by some form of equation [2].

## 2.6 Polarization by Reflection

While polarization by reflection lies outside the scope of the problem defined by EPR and Bell, we can demonstrate the power of this model of the photon by showing that it can supply an account of how polarization can happen by reflection. And the description is quite simple: photons impinging on a flat surface, *F*, will flatten and compress, like a snowball impacting a wall. Unlike a snowball, however, the photons will not stick or cling to *F*, nor will they shatter.[18] Instead, the photon will compress until it becomes sufficiently rigid to rebound from *F*. It will rebound, however, with a new, flattened shape, and the collision will have stopped any spin that the photon had prior to impact because such a large portion of the photon's surface area will have been in contact with *F* for the duration of the photon's compression. If a stream of unpolarized photons (such as that described above in section 2.1) is directed at *F*, each photon will successively be reflected, and each will have a similar, disc-like shape, and those discs will all be aligned

17 Readers new to this topic may then wonder why this paragraph was included at all. The reason is to clarify a matter which confused a great many people who are not new to the topic.

18 In order for a photon to break up, the surface must somehow slice it prior to impact. See the discussion of an absorptive polarizer above for an example of this.

parallel to the impact zone of *F*. In cases such as this, the characteristics which distinguish a polarized beam from an unpolarized beam are summarized in table 3.

We may generalize from Table 3, therefore, and say that polarized beams are streams of photons which are, somehow, ordered. The unpolarized stream presents a variety of shapes, orientations, and spins; the polarized beam is marked by consistency in shape orientation and, if applicable, spin. The final line of table 3 does not rule out the possibility that polarized photons may spin, and rotational polarization is known to occur, so the next section will present the model's account for rotational polarization.

| **Property** | **Unpolarized Beam** | **Polarized Beam** |
|---|---|---|
| Photons aligned in a stream | Yes | Yes |
| Photons uniformly shaped | No | Yes |
| Photons lie in parallel planes | No | Yes |
| Each photon has a uniquely directed spin | Yes | No |

**Table 3:** Summary of differences between photons in polarized and unpolarized beams.

## 2.7 Rotational Polarization

Even if it were not observed, we could not rule out rotational polarization as a possibility because it would always be possible for an observer (conceived as a monadic point) looking at an oncoming non-rotating polarized beam in a universe which consists only of this observer and this beam of light,[19] to see it as rotating because the observer was rotating.[20]

19 We have to restrict the example to this bare-bones universe in order to forestall objections from adherents of Einstein's relativity theory.

A physical body, *G*, can be made to rotate by removing it from contact with other physical bodies (a ball in your hand is less likely to rotate, or sustain a rotation, than one that is tossed into the air), and striking it with another physical object whose trajectory of impact is not in line with the center of mass of *G*. Under such a circumstance, *G*'s center of mass acts as a fulcrum, and the point of impact acts like a weight on a lever. Once initiated, the rotation will not stop of its own accord.

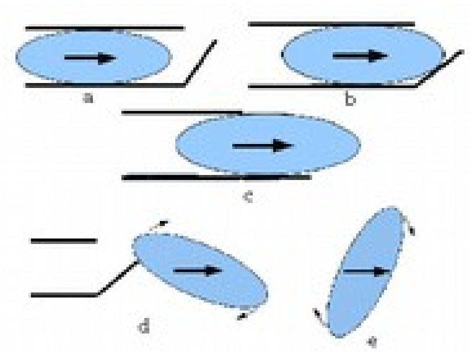

**Figure 6:** Photon passes through channel (*a*) with flexible 'gate;' at (*b*) photon pushes gate open, and passes through (*c*). 'Gate' springs shut at (*d*) striking tail end of photon, inducing spin. Free of the channel, the photon spins (*e*).

If we attach, at the opening on one side of the channels, a flexible, obstructing arm with insufficient resistance to impede the progress of a photon, but with sufficient elasticity to restore itself to its obstructing position as soon as the photon passes, then this arm can swipe the back end of each emerging photon, imparting a spin to them. Since the impact always comes from the same direction and with the

20 Or, to say this more precisely, because there was a relativistic rotation between the observer and the beam—this universe does not really allow one to assign (except arbitrarily) the rotation to the beam, or the observer, or to the contributions of both.

same force, the induced rotations will all be in the same direction (about parallel axes), and at the same rate. Since this spring-like arm must operate on the molecular[21] level, we can provide the necessary combination of flexibility and recoil by positing that the 'arm' is attached to the crystal by a weak molecular bond, and that its rest state (obstructing the channel) results from the balance of electrical charges which are weak enough to be overcome by the advancing photon. See figure 6.

### 2.8 A Wave Model

These days, one must be prepared to explain quantum phenomena both in terms of the behavior of particles and in terms of the behavior of waves. While it is most likely that photons are, in fact, waves, furnishing a wave model which nicely approximates reality will require a serious reworking of the theory of relativity. That theory, so handy for practical purposes, has always been confused and is growing a bit old, but it is so enamored both by professional physicist and those amateurs with an interest in the field, that pointing out its shortcomings, howsoever it might serve the quest for the truth about the world, currently only serves to win one much enmity.[22] The wiser course, then, is to let the

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21 It is clear from the previous discussion regarding the crystal-shaped cells which separate the channels through which the photons pass that the photons do not interact with material bodies on the atomic level, but on the molecular level (this does not, however, prevent them from imparting energy to electrons in cases such as, for example, the photoelectric effect—the photon impacts the molecule as a whole, but individual pieces may express that impact more vigorously than others; the same thing can happen if you toss a beach ball at a crystal chandelier: the metal frame may hardly budge, but the crystals may shake violently or even fly off in various directions.

22 There is an exception to this rule: aficionados often point out some of the peculiarities of the theory and are not censured for it because they show these flaws off as proof that the theory is truly inscrutible. In this regard they are like a doting mother so enamored with her spoiled

lover enjoy his beloved, and await the day when the clouds and fog of passion dissipate.

Consequently, all we need do here is provide a way to understand the discussion in sections 2.1-2.7 in terms of waves rather than particles. This, it turns out, can be done rather simply.

A wave, such as those on surface of the ocean, can be nicely modeled at home by laying a broomstick across a table, placing a towel, or other cloth over the broomstick, and then sliding the stick in a direction parallel to the top of the table and at some non-zero angle to its length: the stick causes a moving bulge in the cloth which models a wave.

To get something more like a wave in a three-dimensional space, we can substitute another cloth for the table, so that both the top and bottom cloth show displacements as the broomstick moves. To better approximate our model for photons, we can envision something like a foot or a ball inserted into an elastic stocking: again, the motion of the ball causes a wave-like displacement of the surrounding cloth.

We can take this model to the next step by thinking about the fact that an object moving through the air must displace the air as it passes, and this would be particularly instructive if we thought of the surrounding air not as a collection of disparate particles (although we know that to be the case) but as a continuum (which is easy enough, since this is the way it is perceived). These considerations can lead us to the final step, for everyday experience often allows one to disregard the presence of the air entirely, so that we can think of a photon as merely a moving three-dimensional

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child that she views his rudeness as frankness, his bullying as proof of strength, his gluttony as a healthy appetite, the things he greedily grabs as entitled property, and so on, always misperceiving vice as virtue.

surface (that is, without regard to whatever stuff it is made of internally), but one which is organically attached to the space through which it moves. Thus, the space has to part and make way for the surface as it approaches, and then it must seamlessly restore itself to its original condition once the photon passes. On this understanding, it does not matter one bit if the photon is spherical or has the most intricate shape, nor does it matter if the photon is rotating or not: whatever behavior the surface of the particle exhibits, the immediately surrounding space must show all these attributes (for there is literally nothing in-between the photon's surface and the surrounding space that it is in contact with). Additionally, if the photon changes shape, the 'wave' in the surrounding space immediately takes the identical shape. On this view, then the difference between a particle and a wave boils done to whether one thinks of the photon as a physical body moving through empty space (allowing the body to interpenetrate the space) or as a geometrical surface moving though empty space  (without allowing for interpenetration).

These considerations, therefore, allow us to immediately transfer everything we said above about photos as particles to a wave model. Figure 7 provides a helpful illustration.

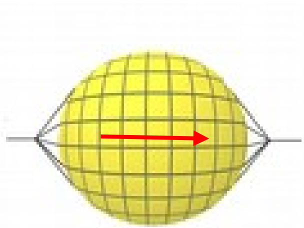

**Figure 7:** Accommodating the wave-particle duality: for the particle model, consider the ball and not the surrounding grid; for the wave model, consider the grid and not the ball. To produce more interesting wave-forms, change the ball's shape and make it rotate.

## 3. Modeling the CHSH Experiment

For the CHSH experiment (named for Clauser, Horne, Shimony, and Holt, the four experimentalists who devised it), we need two birefringent polarizer models, and a supply of model photons. The 'photons' have to pass through the polarizers with more or less the same rotation rates and the same forward velocities. One way to control this is to drop the 'photons' from a standard height. Of course, the 'photons'' paths of descent will have to be aligned so that they are sure to pass through the 'polarizer'. Dropping each through a pipe may be a good way to aim them with some accuracy. Inducing spin may be achieved by causing the 'photons' to graze against an obstacle as they fall (the further down from the drop-point that the obstacle is placed, the more forward speed the 'photon' should have when it strikes the obstacle, leading to a faster rate of spin). One problem with this approach is that it won't induce a spin that is faster than the rate of descent, so a motorized wheel may have to serve as this spin-inducing obstacle. Another key feature of the CHSH experiment (and others like it) is the rotational settings of the polarizers. We can consider the path of the photons as determining the axis of rotation for the polarizer, so, if we are using pipes to direct our 'photons', we can simply attach a pipe to each 'polarizer': turning the pipe (like a steering wheel) turns the 'polarizer'—if we do this, we'll have to induce spin before 'photons' enter the pipe in order to keep spin independent of the orientation of the polarizers.

At this point, we are ready to follow the instructions for a CHSH test: positioning the 'polarizers', pairing up and separating the 'photons', inducing spin, sending them through the polarizers, recording results, and so forth.

Variant tests, such as sending a 'photon' through a succession of 'polarizers' are also possible.

Conducting these experiments should require a small amount of money, some construction skills, some free time, a certain amount of carefulness, and diligent record-keeping. As the author has been blessed with either money or time (but never both together), he humbly requests readers (or, more specifically, those who can) to conduct such experiments themselves.

## 4. Conclusion

By modifying current models for photons so that they behave much like plastic macroscopic bodies, and by modifying current models for polarizers, we have developed mechanical models which can duplicate the results obtained in EPR-Bell tests on photons. These models, coupled with the mathematics of directional similarity, render the behavior of photons intelligible. At the moment, however, these models remain as descriptions or products of the imagination which can serve to explain photon behaviors by analogy. Those with access to appropriate materials, plus sufficient time, interest and means, are invited to build and test physical models on the basis of the designs specified here.

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# Models for Violations of Bell's Inequality

Is it possible to build a model that produces results that mimic those we find in Bell-Tests?

Physicists say, "No."

We beg to differ.  Inside, you'll find guidance on how to model photons (as particles or waves) absorptive polarizers, and birefringent polarizers, as well as get a glimpsof how they operate and interact once put into action. The solution to the so-called 'deepest mysteries' of Quantum Mechanics lie here at your fingertips.

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