Was Einstein Wrong? The Difference between Things We Don't Know and Things We Can't Know

Brigham Young University Forum Lecture
R. Steven Turley
July 27, 2004

I'm really pleased to see all of you here today! My research students tell me that starting up a physics conversation with a stranger is usually not the best way to encourage a relationship. As a matter of fact, even introducing themselves as physics majors can have undesirable social consequences. Image how the conversation might start:
"Hi, my name is Bill, what's yours?"
(big smile)
"Hi, Bill, I'm Lisa. I notice you're carrying a trumpet. Are you a music major?"
(maybe this could go somewhere)
"As a matter of fact, I am. What are **you** majoring in?"
"Physics"
"Oh, bye."

My dream is that you'll catch a glimmer today of how exciting and fascinating the physical world is. Perhaps you'll even want to see me afterwards for a referral of a physics student who'd love to spend a romantic evening with you telling you more.

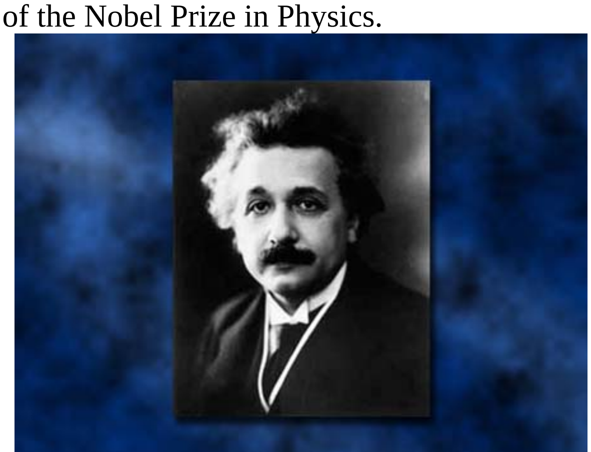
One of the reasons I find such a joy in studying God's physical creations is simply because they are the work of His hands. The Doctrine and Covenants reminds us that the scriptures "are not of men nor of man, but of [Christ]…" Christ explains that "it is [His] voice which speaketh them unto [us]; for they are given by [His] Spirit unto [us], and by [His] power [we] can read them one to another; and save it were by [His] power [we] could not have them; Wherefore, [we] can testify that [we] have heard [His] voice, and know [His] words." (D&C 18:34-36). I feel the same way about the physical world. In it I indirectly see His hands and marvel at the wonder, order, elegance, symmetry, and beauty of His world. Not surprisingly, I find many parallels between principles I see manifest in God's physical creations and the revealed truths He has given us about how we should interact with each other and with Him. I suspect this is partly because "all things are created and made to bear record of [Him], both things which are temporal, and things which are spiritual; things which are in the heavens above, and things which are on the earth, and things which are in the earth, and things which are under the earth, both above and beneath: all things bear record of [Him]." (Moses 6:63) I feel another reason the physical world shows patterns that match those of eternal truths are that God's hands are in both.

A fruitful place to look for insights we might miss in our everyday world is in the realm of things which are very small. At the end of my talk, I will discuss some of parallels I see in the life of the microcosmos that apply to human interactions. These include the connectiveness we have to each other; the importance of relationships in communities, families and in the church; and our accountability for personal choices.

When things are the size of atoms, they have a behavior that is remarkably different from what we are accustomed to experiencing with people-sized things. To picture what I mean, imagine waking up in a world where people could walk through walls; where objects suddenly jump from one place to another; where balls thrown at holes in an arcade game could pass through more than one target at a time; and where the tighter you tried to hold a handful of coins the more they would jump around in your hand. If you found yourself in such a place, you would probably question your sanity. However, this is exactly the kind of behavior we see in the strange world of the small.

Quantum mechanics is the mathematical framework used by physicists and chemists to describe the unusual behavior of these systems. In this address, I will refer to particles whose behaviors require quantum mechanics for their accurate description as quantum particles. The predictions of quantum mechanics are probably the most accurately and broadly confirmed theories in science. However, in spite of its uncanny predictive accuracy, the metaphysical interpretations of the theory are still a matter of open discussion.

Two of most prestigious participants in this debate have been Albert Einstein and Neils Bohr, both recipients of the Nobel Prize in Physics.



Albert Einstein, probably the best known physicist of the 20th Century, spearheaded revolutionary advances in how physicists understand space and time. In 2005, we will celebrate the World Year of Physics, timed to coincide with the centennial anniversary of three seminal papers Einstein published in 1905 on light quanta, Brownian Motion, and special relativity. Paradoxically, his discovery of light quanta played an important role in the development of quantum mechanics.

Nonetheless, he never came to accept the orthodox interpretation of quantum mechanics promoted by Niels Bohr and his colleagues in Copenhagen. So who was right, Einstein or Bohr? Is it possible that the brilliant icon who brought us so many seminal modern physics ideas could have been wrong about the meaning of quantum mechanics?

Let's get to the essence of the two arguments.

The Copenhagen Interpretation of quantum mechanics holds that the behavior of quantum particles is intrinsically random. The results of some experiments are unpredictable until an actual measurement is made. In other words, the state of a particle before a measurement is not only unknown, but unknowable. This interpretation turns questions that have definite answers for classical particles into ones requiring probabilistic answers:

- Consider for example an experiment where a particle is aimed at a target with two closely spaced slits. Which slit does it pass through? (It has a probability of passing through both.)
- Where is the innermost electron in an atom? (It has an equal probability of being anywhere on the surface of a sphere.)

But once you make a measurement in quantum mechanics, the answer becomes definite:

- If you detect which slit the electron goes through, it will always be one or the other, not both.
- If you measure the location of the innermost electron in an atom, it can always be found in a specific location, not spread out in some kind of cloud.

In addition to this randomness, Bohr's Principle of Complementarity and Werner Heisenberg's Uncertainty Principle imply that it is impossible to measure certain pairs of attributes simultaneously. For instance, one cannot precisely determine both the position and speed of a quantum particle no matter how accurate the measuring devices might be. If you take a particle of light, called a photon, and compress it so that it arrives at a very precise time, the color of the light can take on a wide range of possibilities.

If this kind of behavior happened on a macroscopic scale, we would think it was ludicrous. (In fact, some of my students make the same claim about this behavior on a quantum level. I chuckle when I recall a conversation I heard between two friends, one entering and one leaving a Physical Science 100 class where quantum mechanics was being discussed: "If you thought Special Relativity was weird, just wait until you hear what the professor has to say today!"). Imagine a quantum mechanical softball game where the umpire calls "Strike! (maybe)"; or a quantum mechanical driver who found her car spread out between Provo and Payson when she tried to keep her speed close to the speed limit.

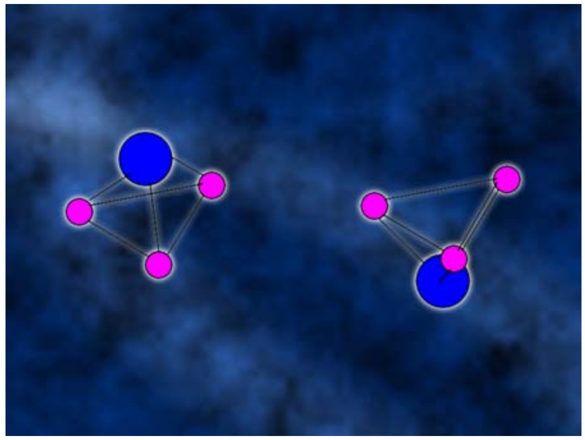
Einstein agreed with my Physical Science 100 student, arguing that a philosophy like Bohr's was too contrary to common sense to be valid. He insisted that the same predictability we see in our every-day world should continue to hold at small length scales. He argued, in particular, that we should preserve two properties abandoned in the Copenhagen Interpretation: deterministic behavior and locality.

Deterministic behavior means that if I were to know everything possible about a particle at one moment of time and how it interacts with other particles, I could precisely predict what would happen to it in the future. This was the situation believed to exist in physics going back at least as far as Isaac Newton. We use this all the time in our everyday lives:

- We confidently assume that the laws used to design the airplanes we board will keep them airborne during our flight.
- We would be most surprised if a dropped book were to fall up instead of down, as it usually does.

Einstein maintained that the apparent randomness of quantum mechanical measurements was not due to an intrinsic randomness in nature, but rather to our lack of complete knowledge about the state of the particles we were measuring. If we only knew everything there was to know about these particles (including so called hidden variables giving rise to apparent random behavior) we could predict exactly what they would do. On the other hand, Bohr, and other members of the Copenhagen School, continued to argue that the precise state of the particle was indeterminate until it was measured. Many outcomes of certain experiments were possible until the actual moment a measurement was made and the particle had to commit itself to a precise outcome.

Locality prescribes a precise position to particles. At a given point in time, an electron has a precise location in its orbit around an atomic nucleus.



The nitrogen atom in an ammonia molecule is either above the triangle formed by the three hydrogen atoms or below it, not in some state like the Nobel Duke of York's troops where it is neither up nor down. Bohr held that the electrons in an atom and a nitrogen atom in an ammonia molecule had no precise, localized position, but had a probability of being found in a range of locations.

Up until the middle of the last century, this left the physics community with an interesting dilemma: we had a very precise physical theory which made predictions that agreed exactly with detailed measurements, but often only in a probabilistic way. The probabilities in the system were precisely determined, but the results of specific experiments often weren't. While the theory was accurate, was it complete? Was it possible to find an equally accurate, but more complete description of nature (as advocated by Einstein) that could precisely predict events for which quantum mechanics could only provide probabilities? Who was right, Einstein, Bohr, or possibly neither?

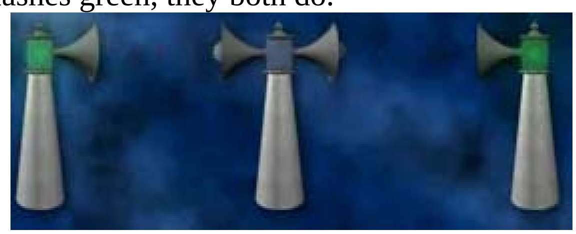
To help illustrate the concepts involved in this debate and its historical development let's consider a simple model developed by David Mermin that encapsulates the essence of both the theoretical and experimental aspects of this question.

Imagine a source that emits quantum particles in opposite directions. I let the particles travel for a while before striking two detectors which will flash red or green. The detectors are arranged so that there is no connection between them and no way to pass a signal from one to the other between the time one particle is detected and the time the other is detected. Such an arrangement is possible because Einstein's Special Theory of Relativity prohibits information from traveling instantaneously from one point to another. It can never be transmitted faster than the speed of light.

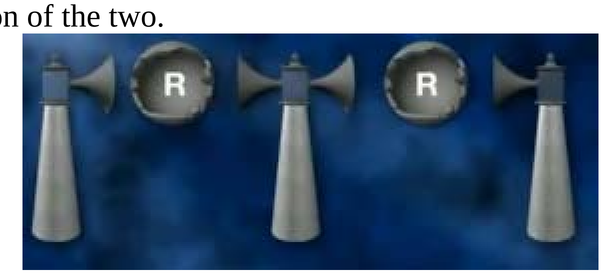
The particles make the detectors turn green or red in an apparently random fashion, flashing green about half the time and red the other half.

All of the statistical tests I apply to this experiment find no pattern that would permit me to predict whether the next flash would be red or green. From one flash to the next there is an equal likelihood of a "red" or a "green."

So far the description of the experiment may not seem very remarkable. But, the particular emitter I have chosen (and there are several realizable physical possibilities to choose from), always emits particles that produce exactly the same color in both detectors. If the detector on the left flashes red, so does the one on the right. If the detector on the right flashes green, they both do.



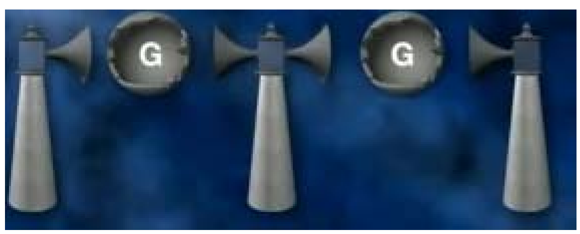
With the emitter I have chosen, this behavior is both predicted by quantum mechanical theory and seen experimentally. The interesting question is why such behavior is seen. Einstein took the position that likely seems the most sensible to the majority of you. If the particles always produce the same color in both detectors they must have some kind of property that is the same for both particles. Both particles are either red or both green, not some combination of the two.



Otherwise, if one particle could flash either red or green, how would the other one know it had to make the other detector respond in exactly the same way?

Bohr maintained that the particles continued to have a probability of producing either a red or a green response in the detector, but that once one particle was detected as being red or green, the other no longer had a probability of producing either color, but rather had to be one that matched its pair.

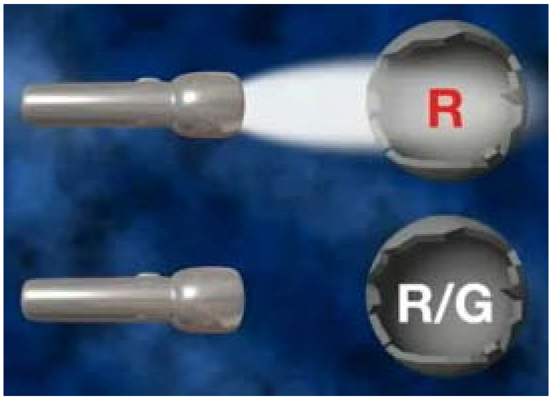
This experiment captures the essence of an analogous situation described by Einstein and his two collaborators, Boris Podolsky and Nathan Rosen. It has come to be known as the EPR experiment, using the letters of the last names of the three authors in this famous paper, Einstein, Podolsky, and Rosen. They argued that the only way these two particles traveling in opposite directions could produce identical results in the two detectors would be for them to both carry some hidden information about whether the detector would be red or green when they arrived. The experimenter might not know the result until the measurement was made, but the particles themselves would have this information already encoded in them somehow in order to produce the agreement when they arrived at their separate detectors.



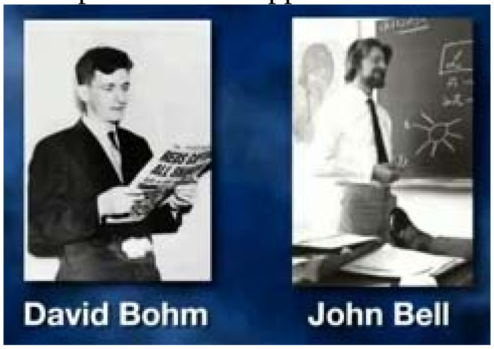
In other words, they would have had to leave the emitter in either a "red" state or a "green" state. The randomness an experimenter observes in the pattern is produced by the emitter. Our inability to predict the experimental result was simply because we had not yet determined whether the two particles were "red" or "green."

Bohr continued to maintain that the "redness" or "greenness" of the two particles was not determined until a measurement was made. The correlation between the two results was established when the particles were emitted (requiring both results to be the same), but the color of the result was not settled upon until the time of measurement.

Although the philosophical standpoints of these two geniuses were distinct, it appeared that this question would not be something that could be settled by a physical experiment. How could one experimentally establish or refute Bohr's assertion that a state was not fixed until the point of measurement? It reminds me of the dilemma I faced as a small child when I imagined a monster in my bedroom who only materialized when the room was pitch dark. I suspected he might be there, but could never discover him by flipping on the light.



"Shining a light" on the quantum particles to discover whether they were "red" or "green" would force them to commit to "redness" or "greenness," destroying their previously indeterminate state. Repeating the experiment with an identical particle under identical conditions could have produced the opposite result.



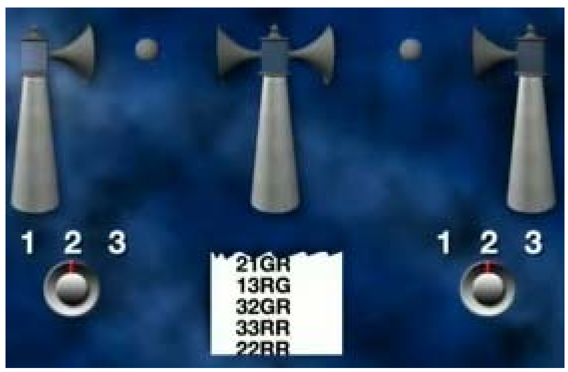
Some progress was made in resolving this dilemma by David Bohm and John Bell in the last half of the twentieth century. Translating their work to our model, they proposed adding switches to the two detectors. After the particles leave the emitter, but before they are observed, a random position is chosen for each of the two switches.

If the switches are in the same position in both of our detectors, the experiment is identical to the EPR experiment. If they are in different positions, the lights do not necessarily flash the same color.

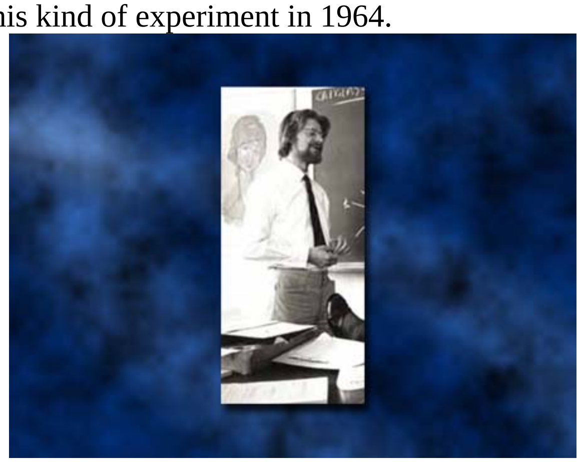
Let's run the experiment slowly a couple of times to see how it works…

Our experiment records the position of the switches for each pair detected and the colors of the flashing detector. For instance, on this shot, the switch on the left is in position 1 and the one on the right in position 2. The left detector flashed green and the right detector flashed red. With the second set of particles, both switches are randomly chosen to be in position 3. In this case, both detectors flashed the same color, red.

Now let's let our model experiment run for a little while and see what cumulative statistics we observe.

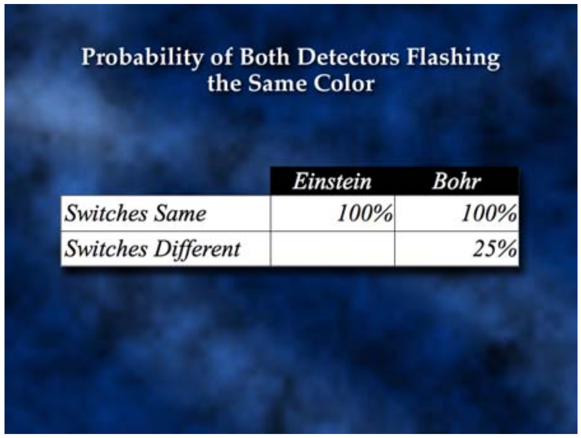


While the statistics in our experiment are accumulating, I'll explain the brilliant analysis John Bell applied to this kind of experiment in 1964.



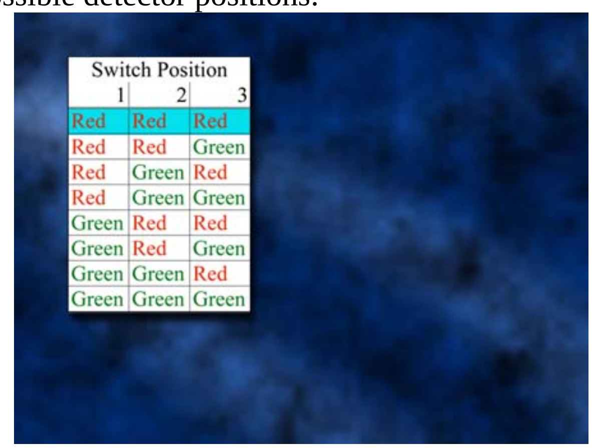
Bell noted that the statistics for getting the two detectors to agree when the switches were in different settings differed for the case of Einstein's hidden variables and Bohr's interpretation.

Let's build a table we will need later to summarize our results. In either Einstein's or Bohr's interpretation, if the switches are in the same position, both detectors will always flash with the same color. Thus, in these cases, the probability of getting the same color is 100%. If the switches are in different positions, quantum mechanics and the Copenhagen Interpretation give a probability of 25% for both detectors to have the same color.



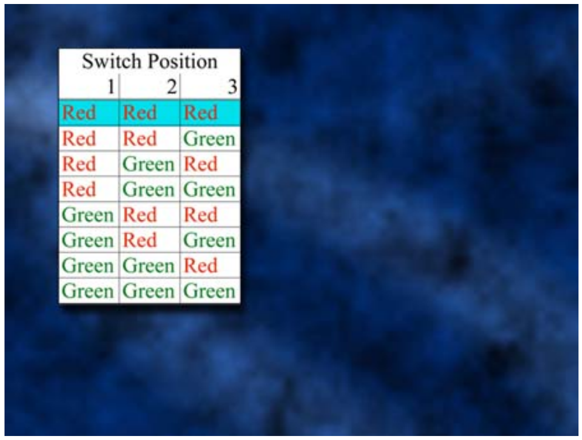
	Einstein	*Bohr*
Switches Same	*100%*	*100%*
Switches Different		*25%*

Filling in the last box in our table requires a little work, but it is worth the effort since it provides the crux of my entire argument. This is the case for when the two switches are in different positions, but the particles have hidden variables determining whether they will produce a red or a green signal in a detector (depending on the position of the switches). David Mermin argues that the only way this hidden information could be encoded is equivalent to a series of interior codes for how the particles would respond to any particular setting of the switches. Each particle has to have identical codes because the particles don't know how the switches will be positioned until it is too late for them to communicate with each other any more. Let's enumerate the possible values of these codes for the three possible detector positions:



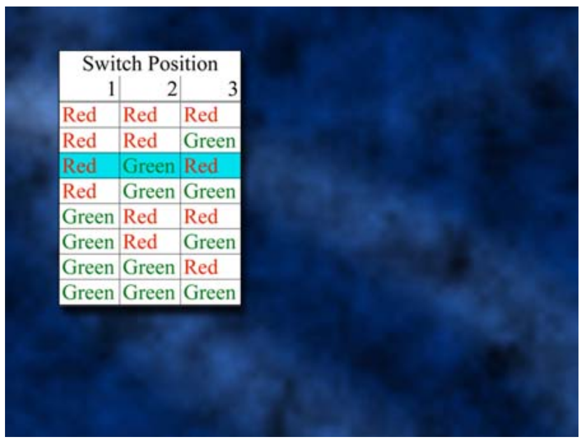
Switch Position		
1	2	3
Red	Red	Red
Red	Red	Green
Red	Green	Red
Red	Green	Green
Green	Red	Red
Green	Red	Green
Green	Green	Red
Green	Green	Green

Each row in the table represents a different possible code the particles could have. For instance, the code in the first, highlighted, row of the table would represent a code where the two detectors would flash "red" regardless of the position of the switches. It has a red signal for the switches in position 1, position 2, or position 3.



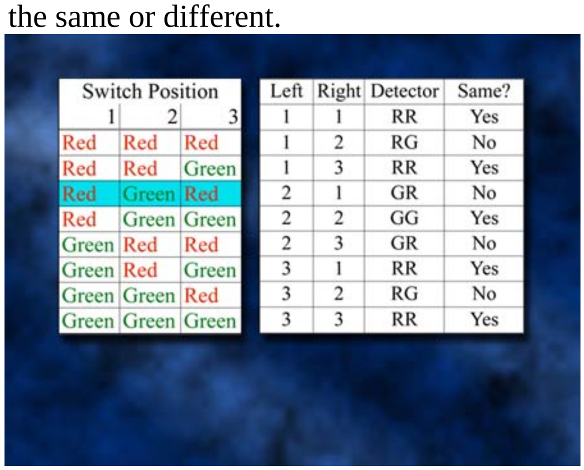
Switch Position		
1	2	3
Red	Red	Red
Red	Red	Green
Red	Green	Red
Red	Green	Green
Green	Red	Red
Green	Red	Green
Green	Green	Red
Green	Green	Green

The third row represents a possible particle code where the detectors would flash “red” if a switch is in position 1 or position 3, but “green” if a switch was in position 2. In other words, the following results would be obtained for the two detectors with the given switch settings in this case.



Switch Position		
1	2	3
Red	Red	Red
Red	Red	Green
Red	Green	Red
Red	Green	Green
Green	Red	Red
Green	Red	Green
Green	Green	Red
Green	Green	Green

The first two columns give the positions of the switches for the left and right detectors. The third column gives the colors the two detectors will flash. The last column indicates whether the colors are the same or different.



Switch Position		
1	2	3
Red	Red	Red
Red	Red	Green
Red	Green	Red
Red	Green	Green
Green	Red	Red
Green	Red	Green
Green	Green	Red
Green	Green	Green

Left	Right	Detector	Same?
1	1	RR	Yes
1	2	RG	No
1	3	RR	Yes
2	1	GR	No
2	2	GG	Yes
2	3	GR	No
3	1	RR	Yes
3	2	RG	No
3	3	RR	Yes

The first row in the table has both switches in position 1. In this case, both detectors will be red (as indicated in the highlighted row in the table on the left), so the Detector column says RR (for red, red). Since both are red, the last column indicates that they are the same color.

Switch Position		
1	2	3
Red	Red	Red
Red	Red	Green
Red	Green	Red
Red	Green	Green
Green	Red	Red
Green	Red	Green
Green	Green	Red
Green	Green	Green

Left	Right	Detector	Same?
1	1	RR	Yes
1	2	RG	No
1	3	RR	Yes
2	1	GR	No
2	2	GG	Yes
2	3	GR	No
3	1	RR	Yes
3	2	RG	No
3	3	RR	Yes

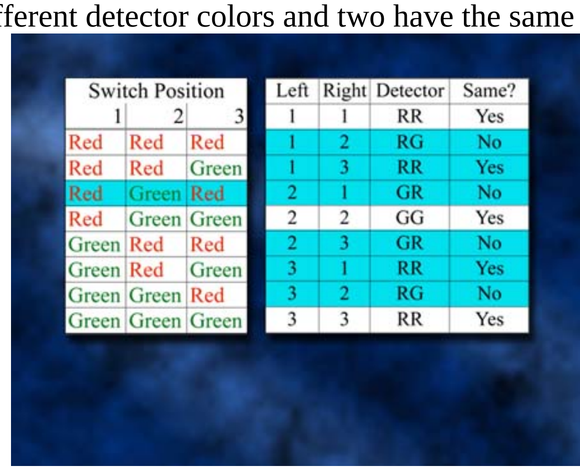
The fourth row in the table is for the case when the left switch is in position 2 and the right switch in position 1. In this case the left detector will be green and the right detector red. The last column indicates that the results in the two detectors are not the same.

The most interesting data in this table is where the switches are in different positions. These are the ones we are trying to compare to the Copenhagen predictions.

Switch Position		
1	2	3
Red	Red	Red
Red	Red	Green
Red	Green	Red
Red	Green	Green
Green	Red	Red
Green	Red	Green
Green	Green	Red
Green	Green	Green

Left	Right	Detector	Same?
1	1	RR	Yes
1	2	RG	No
1	3	RR	Yes
2	1	GR	No
2	2	GG	Yes
2	3	GR	No
3	1	RR	Yes
3	2	RG	No
3	3	RR	Yes

Four of these have different detector colors and two have the same colors.



Switch Position		
1	2	3
Red	Red	Red
Red	Red	Green
Red	Green	Red
Red	Green	Green
Green	Red	Red
Green	Red	Green
Green	Green	Red
Green	Green	Green

Left	Right	Detector	Same?
1	1	RR	Yes
1	2	RG	No
1	3	RR	Yes
2	1	GR	No
2	2	GG	Yes
2	3	GR	No
3	1	RR	Yes
3	2	RG	No
3	3	RR	Yes

In other words, if this were the only code the particles carried, 33% of the time when the switches were different, the colors would be the same and 67% of the time they would be different.

If you go through all eight of the possibilities for codes the particles could carry, they separate into two classes.

Two of the codes (Red, Red, Red) and (Green, Green, Green)

Switch Position		
1	2	3
Red	Red	Red
Red	Red	Green
Red	Green	Red
Red	Green	Green
Green	Red	Red
Green	Red	Green
Green	Green	Red
Green	Green	Green

Left	Right	Detector	Same?
1	1	RR	Yes
1	2	RG	No
1	3	RR	Yes
2	1	GR	No
2	2	GG	Yes
2	3	GR	No
3	1	RR	Yes
3	2	RG	No
3	3	RR	Yes

Same: 2/6 33%
Different: 4/6 67%

have all three colors the same. In these cases the two detectors will agree 100% of the time.

The remaining codes have two colors the same and one different.

Switch Position		
1	2	3
Red	Red	Red
Red	Red	Green
Red	Green	Red
Red	Green	Green
Green	Red	Red
Green	Red	Green
Green	Green	Red
Green	Green	Green

Left	Right	Detector	Same?
1	1	RR	Yes
1	2	RG	No
1	3	RR	Yes
2	1	GR	No
2	2	GG	Yes
2	3	GR	No
3	1	RR	Yes
3	2	RG	No
3	3	RR	Yes

Same: 2/6 33%
Different: 4/6 67%

These all have the same probabilities as the single case we looked at earlier, 33% of the time the detectors will flash the same color and 67% of the time they will flash different colors.

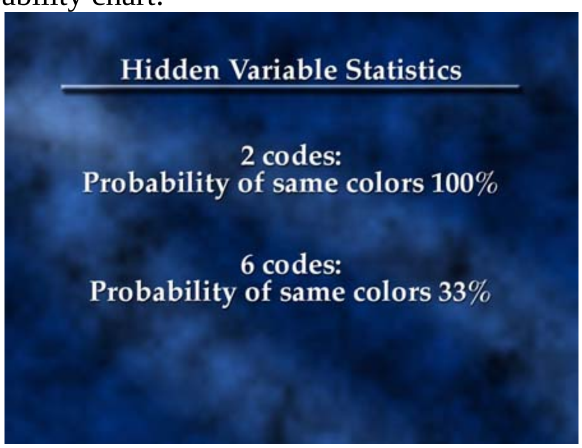
For those of you who are not accountants or statisticians, you may be getting a little dizzy about how. Be patient, we're almost done…

Switch Position		
1	2	3
Red	Red	Red
Red	Red	Green
Red	Green	Red
Red	Green	Green
Green	Red	Red
Green	Red	Green
Green	Green	Red
Green	Green	Green

Left	Right	Detector	Same?
1	1	RR	Yes
1	2	RG	No
1	3	RR	Yes
2	1	GR	No
2	2	GG	Yes
2	3	GR	No
3	1	RR	Yes
3	2	RG	No
3	3	RR	Yes

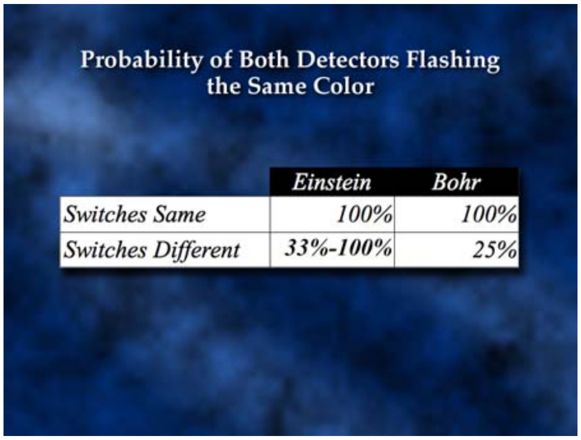
Let me summarize:
In the case of hidden variables, 2 possible particle codes have a 100% probability of producing the same colors in the detectors and 6 codes have a 33% probability of producing the same colors.

So, what will we see when we do the experiment? Well, we don't really know how the different possible codes would be distributed, but we could look at the range of possibilities. If the codes have all of the colors the same, the two detectors would always flash the same color. If the codes never had all three colors the same, we would see the same colors 33% of the time. If there was a mixture of the two codes, we would see the same colors somewhere between 33% and 100% of the time. We can finally fill in the last square in our probability chart:



If you fell asleep during all of the statistics, now is the time to wake up. This table summarizes the remarkable results of John Bell. It shows that we can experimentally tell the difference between the philosophical foundations of quantum mechanics proposed by Einstein and Bohr. All we need to do is conduct a real experiment analogous to the one I have proposed and see what we get.

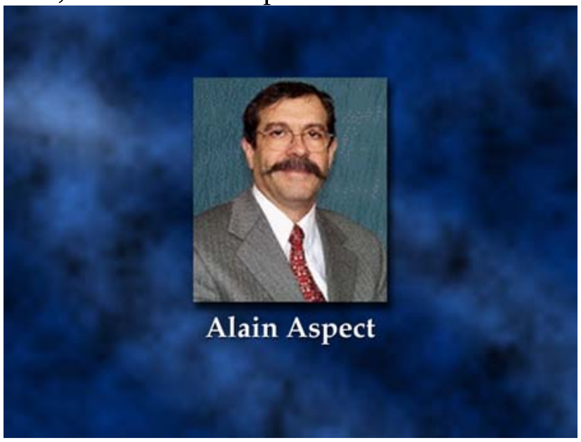
When I showed this result to Dennis Packard, a friend of mine in the Philosophy Department, he was delighted. He called it experimental philosophy, something he didn't imagine he'd ever see.



	Einstein	Bohr
Switches Same	100%	100%
Switches Different	33%-100%	25%

The most convincing experiment to gather the type of data predicted in our probability table was performed by Alain Aspect, Jean Dalibard, and Gérard Roger in 1982 using pairs of photons (the particles that make up light). Light has a property called polarization which is analogous to the "red" and "green" colors I used in my simple experiment. The switches used by Aspect were very fast optical switches capable of changing the measurement being made in about ten trillionths of a second. Since it took the photons about 40 trillionths of a second to travel from the emitters to the detectors, the position of the switch was chosen in a way where the particles could not communicate the state of the switch to each other within the limitations of the speed of light. Aspect compared the numbers of photons he detected with the same polarization to those with different polarizations.

In terms of our experiment, this is what Aspect saw:



If switches are in the same position, colors agree 100% of the time. If they are in different positions, colors agree only 25% of the time.

In other words, Aspect's results showed that Einstein's hidden variable theory (which predicted that the color from different switches would agree at **least** 33% of the time) was not consistent with how nature behaves. And the disagreement was spectacular!

	Same Color	Different Color
Same Switches	100%	0%
Different Switches	25%	75%

In a statistical experiment of this sort, you always worry that the result you see might have occurred by chance. The probability of that happening in Aspect's case is so small it is like flipping a coin and getting "heads" 22 times in a row (or hitting 22 consecutive non-synchronized traffic lights green). Another analogy would be trying to spell the word "quiet" by picking five random letters and having it come up correctly.

To answer my original question, "Was Einstein Wrong?" Yes, in this case he apparently was! Was Bohr right? Maybe—there have been several philosophical alternatives to the Copenhagen interpretation which are still consistent with John Bell's Theorem and Aspect's experiments. However, most physicists seem to currently agree with the following:

- Quantum particles are not local: they have probabilities of being in extended regions of space. Furthermore, to some extent their behavior is most often entangled with the behavior of other particles.
- The results of quantum experiments have a randomness that is part of the nature of things the size of atoms. The randomness is not due to what we don't know, but rather what we can't know.

Now, what might the admittedly esoteric philosophical difference between what we can know and what we don't know about the behavior of atoms mean to you? Well, if you'll accept my beginning premise that we would expect to see parallels between the manifestation of God's handiwork in the physical world and in other applications of this law I think there are a number of parallels between the quantum behavior and important spiritual principles. Quantum nonlocality, quantum entanglement, and non-determinsitic systems have their analogs in how we are each connected to each other, the importance of our interpersonal relationships, and free agency.

Just as quantum particles have an influence that extends beyond a single point in space, each of us has an influence that significantly extends beyond our present location in space and time. I would not be quite the same person without the influence of a young friend who taught me about loyalty, a father who taught me about integrity, a mother who instilled a desire to serve and lift others, youth leaders and seminary teachers who added sparks to the kindling of a beginning testimony, missionary companions and leaders who taught me about devotion and diligence, BYU professors who demonstrated how to integrate a drive for academic and spiritual excellence, and (lately) some notable colleagues and students who energize and encourage me with their commitment to truth and have “[His] image engraven in [their] countenances” (Alma 5:14) and “can [still] feel [to sing the song of redeeming love].” (Alma 5:26).

Personally, I’m committed to strive to do all that I can to make the influence I inevitably have on all I encounter a positive one and invite you to do the same. As a teacher and a follower of Christ, I want to be like the city lamplighters before we enjoyed electric streetlights like we do today. You didn’t always know where the lamplighter was, but you could always tell where he had been by the lamps he had lit.

As I mentioned, quantum particles have behaviors that are linked with each other. It requires an unusual amount of effort to prepare particles whose behavior is relatively uncoupled from other particles around them. As a matter of fact, the bulk properties of everyday objects we see around us involve collective behaviors that are very different from properties of the individual constituents. For instance, the temperature and pressure of a gas is a characteristic of a collection of molecules that is absent in the behavior of the individual particles.

Likewise, we are all connected in communities of family, neighborhoods, quorums, and wards. We should learn from our quantum friends to be actively engaged in contributing to and strengthening each of these units. Many influences in our current society seem destructive of family ties, neighborhood cohesiveness, quorum unity, and a general building of Zion within the Kingdom. Quantum particles teach us that these community ties are natural and need to be nourished. Even God’s work and glory is apparently intertwined with our personal salvation and exaltation (see Moses 1:39). If that relationship is so important to Him, shouldn’t our relationships with each other be the same?

Finally, the indeterminacy of quantum outcomes until a measurement has a strong parallel to personal agency and responsibility. As we know from the scriptures, our freedom to choose was guaranteed us by the Father from the beginning. (see 2 Nephi 2:27, for instance) Just as a particle’s response to a measurement is not totally dependant on its surroundings, we too have an opportunity (with an attendant responsibility) to personally determine how we will respond to the various measurements (which we call tests) that we will encounter in this life. As a matter of fact, just as in quantum systems, we define who we are by our response to these tests. The tests aid us in becoming who we want to be as we gradually define ourselves by the choices we make. Our quantum particles don’t assume the characteristics of red and green until tested. We likewise do not assume the characteristics of a disciple of Christ until we encounter the tests which are an integral part of this earthly existence.

So, as you have learned more about the nature of the quantum world, I hope you’ll take lessons into your lives of charity, helpfulness, service, involvement with others, positive responses to daily trials, and an accountability for who you eventually will become.