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BELL'S THEOREM AND PSYCHIC PHENOMENA

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As a teacher of physics, I try to distil exotic theories so as to be understood and appreciated by the largest possible audience. What I recently learned in an advanced quantum mechanics class was so disturbing that I felt compelled to express the concept as simply as possible, without destroying the correctness of the argument. It appears that elementary particles act as if their behaviour were linked by channels of communication that can be best described as 'psychic'.

The philosophical implications of Bell's theorem and the Einstein–Podolsky–Rosen (EPR) paradox have been recognized for several years[1] and are discussed in most modern textbooks on quantum physics.[2] Although quantum mechanics apparently 'resolves' the EPR paradox, we can think about it without using quantum mechanics. In fact, quantum mechanics can so overwhelm a person's common sense that one tends not to think about what is really happening.

It must be understood that we are not talking about a theory, but the results of actual experiments,[3] first performed in 1971. These experiments involve two particles that are simultaneously ejected from a single atom, in opposite directions, as shown in Fig. 1. Previous experiments have used either photons or protons, but for the sake of clarity I am going to invent a hypothetical experiment involving neutrons.

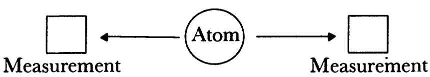

Fig. 1. Schematic of EPR experiment. One atom ejects particles in opposite directions for remote measurements.

It is important to know something about the nature of the measurements made on the particles. In the case of neutrons, the particle might be passed

[1] See, e.g., Bernard d'Espagnat, 'The Quantum Theory and Reality', *Scientific American*, 241(5), November 1979, pp. 158–81, in which a simple proof of Bell's theorem can be found; also James T. Cushing and Ernan McMullin (eds), *Philosophical Consequences of Quantum Theory* (Univ. of Notre Dame Press, 1989).

[2] See Hans C. Ohanian, *Principles of Quantum Mechanics* (New York: Prentice Hall, 1990).

[3] Alain Aspect, Jean Dalibard and Gerald Roger, 'Experimental Test of Bell's Inequalities Using Time-Varying Analyzers', *Physical Review Letters*, 49 (1982), p. 1805.

over the north pole of a magnet which is oriented perpendicularly to the path. For reasons explained by quantum theory, the neutron is deflected either towards or away from the magnet, and always by the same amount, as shown in Fig. 2.

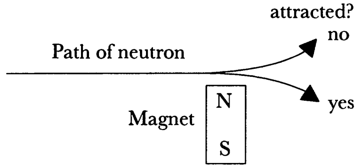

Fig. 2. The measurement consists of passing the neutron over the pole of a magnet. The neutron is either deflected towards or away from the magnet.

The measurement essentially interrogates the neutron, asking 'Are you attracted?'. The response by the neutron is either 'Yes' or 'No'. The measurement can be made in a number of different ways by changing the angle that the magnet makes about the path of the neutron. Fig. 3 shows the experiment seen end on, with the different possible orientations for the magnet, the original path of the neutron and its two possible paths after passing the magnet.

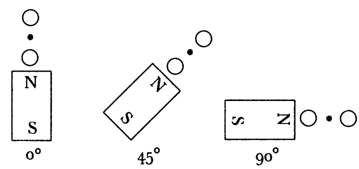

Fig. 3. Different possible orientations for the magnet. The neutron is coming out of the paper, and its path prior to encountering the magnet is the black dot. The two possible paths taken after passing the magnet are shown as circles.

After one measurement, subsequent measurements on the same neutron are of no interest to us. We get to ask each neutron one and only one question. However, since there are two neutrons, we get to ask two questions. And, by choosing the magnet orientations, we get to choose from a number of possible pairs of questions. For our purposes, we restrict ourselves to three possible orientations of the magnet: 0°, 45°, and 90°. Thus we ask each neutron one and only one of the following questions:

Are you attracted to a magnet oriented at 0°?
Are you attracted to a magnet oriented at 45°?
Are you attracted to a magnet oriented at 90°?

It is fascinating that these particles are far apart at the time of the interrogation. One experiment with photons puts a distance of twenty metres between interrogation points. It is generally believed that traditional communication between the particles during interrogation is impossible. There is certainly no known physical mechanism for communication. The experimentalists took the trouble to change the questions so rapidly that any such 'communication' between particles would require information to travel faster than the speed of light. Such 'superluminar' communication violates the principle of causality, which says that it is impossible to change the past.[4]

[4] See Edwin F. Taylor and John A. Wheeler, *Spacetime Physics* (New York: W.H. Freeman, 1966).

The story of Harry and Sally

Let us anthropomorphize the situation by labelling the particles with the names of two people, Harry and Sally. We shall also change the questions to something that a human might appreciate. As any logical person will recognize, this re-labelling does not change the fundamental paradox inherent in Bell's Theorem. Harry and Sally are being investigated by researchers in psychic phenomena who have constructed two sound-proof isolation chambers, designed so that no information can leave or enter once the doors are shut. Every morning, Harry and Sally enter separate isolation chambers and each is asked one question, randomly selected from the following list:

Are you hungry?
Are you thirsty?
Are you happy?

The experiment is repeated every day for many years, and the results are tabulated. Sally and Harry may or may not be asked the same question on any given day. Before entering the isolation chambers, neither knows which question will be asked. Sally and Harry are unable to communicate with each other during the interrogation.

After their daily interrogation, Sally and Harry leave their isolation chambers and go on with their usual daily routines. It is understood that Harry and Sally are under no obligation to tell the truth during the interrogation. They are allowed to discuss and plan their answers before and after each interrogation, if they wish.

The results

After looking at the data from a large number of interrogations, the researchers notice that each question is answered 'Yes' 50% of the time, and 'No' 50% of the time. The researchers also observe that the answers are never in violation of the following two rules:

Rule 1. If Sally and Harry are asked the same question, they always give the same answer.

This implies that they consciously or unconsciously knew the answers to all three questions before they entered the isolation chambers. The justification for this claim is that if Harry changes his mind, there is no mechanism by which Sally would know of this so as to change her mind in order to comply with Rule (1). Since both are prepared to give the same answers, there are eight possible sets of answers that they could have prepared each morning before entering the isolation chambers, as shown in Table 1:

Table 1

	Hungry?	Happy?	Thirsty?
1.	No	No	No
2.	No	No	Yes
3.	No	Yes	No
4.	No	Yes	Yes
5.	Yes	No	No
6.	Yes	No	Yes
7.	Yes	Yes	No
8.	Yes	Yes	Yes

Rule 2. There is a pattern among the answers whenever different questions are asked. For example, if one is hungry, the other one is never thirsty. The pattern is summarized in Table 2, which contains six rules which are obeyed whenever different questions are asked:

Table 2

	Hungry?	Happy?	Thirsty?
a.	Yes	—	No
b.	No	—	Yes
c.	Yes	Yes	—
d.	No	No	—
e.	—	No	No
f.	—	Yes	Yes

In Table 2, line (f) says that one is always happy when the other is thirsty. To be more precise, one claims to be happy whenever the other claims to be thirsty. Note that it is never verified that Harry and Sally are in compliance with Rule (1) and Rule (2) on the same day. If both are asked the same question, Rule (1) is verified, and if they are asked different questions, Rule (2) is verified. It is impossible to verify both rules on the same day because only two questions are asked. Only after the experiment has been repeated many times is it clear that both Rule (1) and Rule (2) are never violated.

However, since Sally and Harry do not know in advance which questions will be asked, they must somehow preselect a set of answers that obeys all the rules. But this is impossible! For example, suppose Harry and Sally select item (1) in Table (1). This is in violation of rule (a) in Table (2). The reader is asked to verify that each possibility listed in Table (1) is inconsistent with one of the rules in Table (2).

There are only two mechanisms by which Harry and Sally could always obey both rules. They could communicate with each other while in the isolation chambers, thus changing their story in the middle of the interrogation. Or they could know in advance which questions would be asked. Either mechanism would require psychic powers on the part of Harry and Sally.

It has been clearly stated by experts that the apparent telepathy displayed by neutrons is limited by the fact that we cannot send signals via the interrogations. In other words, if Sally says she is hungry, we cannot ask her if she chose that answer because Harry said he was hungry, or because Harry said he was happy. Sally cannot even say whether Harry was the first to be interrogated. She apparently does not know herself!

Back to actual neutrons

One significant difference exists between an actual EPR experiment and this story. It turns out that Harry and Sally do not always obey the rules of Table (2). In fact, they break Rule (2a) as often as they obey it. It was Bell who in 1965 pointed out that the correlations predicted by quantum theory are impossible without what might loosely be called 'communication' between the particles. These 'impossible' correlations have been observed in a number of experiments.

To put this talk about correlations into everyday language, we have a situation where Harry and Sally have good days and bad days with respect to their 'psychic powers'. However, the good days happen so often that it would defy the laws of probability for them to obey Rules (1) and (2) as often as they do. Imagine, for example, that Harry and Sally obey the rules on only half the days, with the selection of those days being completely random. On those days when Harry and Sally do not obey the rules, they simply give random answers. However, half the time, they obey both rules, thus doing the 'impossible'. Such 'impossible' behaviour could be detected statistically by observing for a large number of days.

Conclusion

Bell's theorem is truly astonishing, more astonishing than the rest of quantum mechanics, which makes bizarre predictions about small objects. According to quantum mechanics, large objects also display this bizarre behaviour, but to a much lesser extent. For example, the 'uncertainty principle' predicts that it is possible for someone to be suddenly and mysteriously transported to a high mountain in Tibet, only to return just as mysteriously. However, a simple estimate indicates that the probability of anyone's being

transported a significant distance is so remote that it will never happen in the age of the universe. In other words, most of the bizarre quantum behaviour attributed to particles is due to the fact that they are so tiny.

On the other hand, there seems to be no fundamental reason why two people could not put themselves into what might be called a 'degenerate-mixed-energy-state' and reproduce what Harry and Sally have done here. I did not intend to write an essay on psychic phenomena, and made this analogy because it is the most direct description of what the EPR experiment is actually doing. I do not believe in mental telepathy, miracles or any other occult phenomenon. This affair with Bell's theorem has shaken me to the bone.

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