Re: A Look at Quantum "Spookiness"

Source: http://sci.tech−archive.net/Archive/sci.physics.particle/2006−03/msg00041.html

---

- *From*: "Tao" <not@xxxxxxxxxxxx>
- *Date*: Thu, 09 Mar 2006 19:43:56 GMT

"Tao" <not@xxxxxxxxxxxx> wrote in message
news:RNLPf.78099$K42.54637@xxxxxxxxxxxxxxxxxxxxxxx

> "Daniel Pitts" <googlegroupie@xxxxxxxxxxxxx> wrote in message
> news:1141832268.396187.111290@xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
>
> > Tao wrote:
> >
> > > "Daniel Pitts" <googlegroupie@xxxxxxxxxxxxx> wrote in message
> > > news:1141519884.557237.169870@xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
> > >
> > > > Tao wrote:
> > > >
> > > > > "Daniel Pitts" <googlegroupie@xxxxxxxxxxxxx> wrote in message
> > > > > news:1141490832.471718.181110@xxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
> > > > >
> > > > > > Tao wrote:
> > > > > >
> > > > > > > "Erops" <erops@xxxxxxx> wrote in message
> > > > > > > news:220df44086508d8080e77$30809@xxxxxxxxxxxxxx
> > > > > > >
> > > > > > > > A Look at Quantum "Spookiness"

The results of quantum theory were described as "spooky" by Drs. Einstein, Podalsky, and Rosen because quantum theory seemed to reject "objective reality". They believed that all observed effects must be produced by "local" causality. Their conclusion resulted from their firm belief that information could not travel faster than the velocity of light. Indeed, if this were the case, quantum theory would indeed be "spooky". Quantum theory required, for example, that "paired photons" maintain polarizations which were opposite in direction. If the polarization angle of one of the "paired photons" were changed, the polarization angle of the other photon of the pair must instantaneously change to match.

Actually this is not a very accurate description of the situation. It is about determining the polarization, not changing it. The key thing is that one can measure the polarization in two directions which are incompatible observables in quantum mechanics, so the results cannot be explained merely by the states the particles started off in. Which direction to measure can be chosen by a central controller communicating simultaneously with each end of the experiment.

If you read the papers about Aspect's experiment (which verified Bell's theorem empirically), as I have, you will see

Bell's result is only visible in the statistics, not in any individual measurement. No−one has found any way to use this effect to communicate faster than light, and very few people expect this to ever happen.

Although, they have proven conclusivly that the aformentioned effect is real. Not by statistics, but by concrete mathimatics. Instead of

coupling
two
photons,
they used
three
photons,
and the
math
became
"Always"
(Quantum
Spookiness)
or "Never"
(Einstein
Hidden
Variables).
Turns out
its
"Always"

It is possible my intended meaning was not clear. The effect is in the statistics of the measurements, and can be seen when one collates the experimental data from both (or all three) afterwards, but at the time, there is no way for any of the participants to use the effect to communicate with another at faster than the speed of light.

One article I read on this said that when a participant makes a measurement it "determines an aspect of reality". This aspect of reality is immediately known at another point connected by quantum entanglement. The reason this

cannot be used to
communicate is that the
person who made the
measurement
did not specify what the
aspect of reality was (for
example, whether
the
photon was vertically
polarised), he merely
measured it. From
measurements
made at the other end, the
other participant cannot
determine
anything
about
what the first person did.
We can only be sure that if
the other
person
measures the vertical
polarisation, his
measurement will be
determined by
the measurement that the
first person made.

Is this clear now?

Yes... But, what if entangled particles are
actually different facets
of the same underlying particle? Maybe
there is no such thing as "one
photon" entangled with another "one
photon". Maybe once they are
entangled, the actually become a single
entity that exists at more
than
one physical point.

Yes, it's absolutely right to think of the two photons as two
parts of a
single quantum mechanical object.(called a pair of coupled
photons)
until a
measurement of the polarization of one of them is made. This
"immediately"

fixes the polarization of the other photon, but also breaks the coupling, in
the sense that nothing you do to one of the photons afterwards will have
any
further implications for the other photon (i.e. if anyone made any
measurements on one of the photons, the new information would not be
useful
to predict what a measurement on the other photon would be.

Fortunately this is made clear by the "bra−ket" formulation due to
Dirac.
When you write down the quantum states, you can see the way two photons
can
be "entangled" and it also shows how when one makes a measurement they
become "untangled".

Let a single photon 1 in a vertically polarized state be:

| V1 >

and a single photon 1 in a horizontally polarized state:

| H1 >

If photon 1 is unpolarized it is a state which is 50% of each:

1/2 | V1 > + 1/2 | H1 >

{ a photon could also be polararized at any other chosen angle, and
these
states can be mixed together in various ways, but that's just confusing
the
issue unnecessarily }

Suppose we start with paired photons of random polarisation. We write
the
state where they are both vertically polarised

| V1 > (x) | V2 >

and the state where they are both horizontally polarised

| H1 > (x) | H2 >

Each of these is what is called a tensor product of the
individual
photon
states. A state that is a tensor product of states of the
individual
photons
is not entangled, because the behaviour of each of the
photons does not
depend at all on anything you do to the other one.

The initial state in the experiment is given as:

1/2 | V1 > (x) | V2 > + 1/2 | H1> (x) | H2 >

Which says there's 50% chance they are both vertically
polarized and 50%
chance they are both horizontally polarized. This is an
"entangled", or
"coupled" or or "correllated" state. This is because it is
impossible
to
write this as a single tensor product of the states of two
different
photons. It is entangled because any measurement of
polarization of one
photon acts on this state in a way which gives you
information about the
other photon.

If we make a measurement of the polarization of one of the
photons in
the
vertical direction, mathematically we apply an operator to
that state
above
and the rules say that we get either:

| V1 > (x) | V2 >

or else

| H1 > (x) | H2 >

{with a real polarizing filter, the latter would be the case
where it
reflected}

Either of these is no longer an entangled state, as it is a
tensor

> > product
> > of the states of two separate photons, so it behaves like two
> > separate
> > photons. No measurement on one photon will tell you any
> > more about the
> > other
> > one.
> >
> > At the risk of being repetitive, if the state of two particles
> > cannot be
> > written as a tensor product of a state of one particle and a
> > state of
> > the
> > other particle, they are entangled.

> That explains some to me, thanks.
>
> So, what happens if I somehow alter (without mesuring) the polarization of one of the photons? Does the other photon change? In other words, given A is entangled with B, if you change A by 10 degrees, does B change by 10 degrees as well?
>
> What about alterations that are unobservable?
>
> Sorry if these are newb questions.

Well the answer in the case we were looking at is this.

starting with the state:

1/2 | 0_1 > (x) | 0_2 > + 1/2 | 90_1> (x) | 90_2 >

i.e. 50% chance that both are polarized at 0 degrees and 50% chance that both are polarized at 90 degrees.

If you make a measurement of the polarization of one photon in _any_ direction, you immediately know what the polarization of the other photon is. For example, if you measure the polarization of the 1st photon in the direction 45 degrees, you either find it is polarized at 45 degrees or it is polarized at 135 degrees (just like horizontal = not vertical, only twisted around a bit).

When you have done this, you immediately know the second photon has the same polarization, either 45 degrees in one case, or 135 degrees in the other. This gives us a state like:

| 45_1 > (x) | 45_2 >

> i.e. both photons are polarized at 45 degrees.
>
> But once you have done this once, the photons are unentangled, and you can't do anything to one photon that tells you anything more about the other one. For instance, once you have found the polarization of both photons is at 45 degrees, if you then measure the polarization of the first photon at 90 degrees, there's a 50% chance you find it is and a 50% chance that it isn't (which means it's polarized at 0 degrees).
>
> But the polarization of the second photon stays at 45 degrees, since it is no longer coupled. So we just get a state like:
>
> | 0_1 > (x) | 45_2 >
>
> or
>
> | 90_1 > (x) | 45_2 >
>
> There are very simple mathematical rules for exactly what happens when you apply any measurement to any sum of tensor products of states that gives exactly the results above.

Unfortunately, I overstated the case above. Doing the calculation, it is clear that one does not get a certain polarization for the second photon for all possible choices of the angle of the filters, just a increased probability in general. My argument for this is as follows:

The rules for measurement on 1 photon are easy. If it is polarized at an angle a and you measure the polarization at angle b , the probabilty is (cos(a−b))^2 that it gives "true" and 1−(cos(a−b))^2 that it gives "false".

i.e. < M(b) | a_1 > = cos(a−b)^2

If you tensor this photon state with the state of another photon, measurements applied to the first photon don't affect the state of the second:

< M(b) | a_1> (x) | c_2 > = cos(a−b)^2 | c_2>

and the rule can be extended to a applying a measurement to one of a pair of coupled photons, by applying it to each component separately:

<M(b)| applied to 1/2 | 0_1 > (x) | 0_2 > + 1/2 | 90_1 >
(x) | 90_2 >

= (1/2)(cos(b))^2 | 0_2 > + (1/2)(cos(90−b))^2 | 90_2 >

so in this case, our knowledge about the polarization of the second photon is only perfect when a measurement was made at either 0 degrees or 90 degrees (180 or 270 degrees are the same, of course).

Unfortunately, the worst case is where we make a measurement at 45 degrees (or 135, 225, 315), when this is:

(1/2)(cos(45))^2| 0_2 > + (1/2)(cos(45))^2 | 90_2 > = (1/4) | 0_2 > + (1/4) | 90_2>

so in this case we know nothing about the polarization of the other photon (any measurement of the polarization of the second photon gives a positive result 50% of the time).

However, it is possible to have situations where _any_ measurement of polarization of the first photon will give some (but not perfect) imformation about the second photon. For example, if we know that the two photons have identical polarization, but no idea what that is, the state is an integral from theta=0 to theta=2*pi of

1/(2*pi) | theta_1 > (x) | theta_2 >

{a state where both photons are polarized at the same random angle theta between 0 and 2*pi}

Measuring the polarization of the first photon at some direction phi gives an integral over theta of 1/(2*pi) (cos(phi−theta))^2 | theta_2 >

Making a measurement of the polarization of the second photon at angle phi gives an integral over theta of 1/(2*pi) * (cos(phi−theta))^4

The ratio of the probabilities (which is the conditional probability that the polarization of the second photon agrees with the measurement of the first) is the ratio of the integral of cos^4(theta) to the integral of cos^2(theta).

This is 0.75.

So, in this case there is a 75% chance that the polarization of the second photon agrees with that of the first, for measurements of polarization in any direction.

Any questions/comments/improvements?

.