

The Saga of Two Gloves.

This tale illustrates one central features(very important) of quantum theory.

You and a friend are at the **airport** in Atlanta.

You each have a **locked box** containing a glove.

One box contains a **right-handed** glove of the pair, the other the **left-handed** glove, but you **do not know** which.

Both of you also have **keys**, but they are **not** the keys to the boxes you are carrying.

Carrying your box, you each **board** a Delta airlines plane.

You fly to **Chicago** and your friend flies, at the same time, to **Philadelphia**.

When you get to Chicago you **use** your key to open a locker at the airport, and inside you **find** another key.

This is the **key** to your box, which you now **open** to discover that the glove you have brought to Chicago is the **right-handed** one.

As **soon as you know** this, of course, you **know also** that your friend's box, by now in Philadelphia, **contains** the left-handed glove.

With that **instantaneous realization**, you have acquired a piece of knowledge about a state of affairs on the other side on the east coast.

Perfectly straightforward, you may say, and so it is.

You may have heard of **Einstein's rule** that nothing, not even information, can travel faster than the speed of light, but **no part** of this story contradicts this rule in any way.

You have **made** a deduction, using information **available** to you at the Chicago airport, about a fact that pertains to your friend in Philadelphia.

We **make this kind** of long-distance inference, in big ways and small ways, all the time.

An **astronomer** observing the weak light that reaches a telescope here on earth uses it to deduce the surface temperature of stars many light years away.

You get out of the shower one morning, **look** at your watch, and realize that a class meeting that you had to attend has already started.

Figuring out what is happening in some distant place is a **different** thing from **transferring** that knowledge from one place to another.

If, having discovered that your glove is right-handed, you wanted to tell your friend that she has a left-handed one, you would have to use a cellphone, or send a telegram, or send her email or mail her a postcard.

Some of these might even travel at close to the speed of light (under ideal conditions).

You have **no way**, however, of knowing whether she has **already** opened her box or not - unless you **get a message** from her telling you that you must have a right-handed glove.

The fact that you have **found out** which glove she has **does not allow** you to beat the laws of physics and get that information to her faster than Einstein allows.

But still, **you think** that there might be **some way of exploiting** your knowledge to influence your friend's behavior.

Suppose, before you both set off on your plane trips, you had **agreed** with your friend that if she found the left-handed glove in her box she **would proceed** onto London, but if she found the right-handed one she would fly to **Paris**.

Does your opening the box in Chicago **determine** where she ends up?

Not a chance!

Whichever glove was in her box **was there** from the outset (**objective reality**), so whether she has to fly to London or Paris is **predetermined**.

When you open your box in Chicago you instantly know where she must be going next, but her destination is **as much a surprise** to her as it is to you.

As before, you **have found out** what happens next, but you have **no influence** over it.

Now let us **change this story**.

The gloves in the two boxes are, you are informed, of a **strange and quantum-mechanical kind**, unlike any gloves you have ever come across before.

They still make up a **pair**, but for as long as they are **sealed up** in the boxes, they are **neither** right-handed nor left-handed, but in an **unfixed, indeterminate state**.

Only when a box is opened, letting in the light, does the glove inside **instantaneously become** either right-handed or left-handed and there is a **50-50 chance** of either eventuality.

During the few hours you are in the plane flying to Chicago, you **may well be puzzling** over what the glove in your box - this strange glove, neither right-handed nor left-handed but **potentially** either - actually looks like.

But you **do not have** the key that would let you open the box and peek inside, and, **in any case**, as soon as you peeked the glove would have to take on a definite shape, right-handed or left handed.

The **quantum-mechanical nature** of the glove is such that you **can never see** it in its unformed state, because **as soon as you look**, it turns(**collapses**) into something familiar and recognizable.

A frustrating catch-22.

On the **other hand**, **as soon** as you arrive in Chicago and open your box to **find**, let us suppose, a right-handed glove, you **begin to think** that things are **not as straightforward** as before.

You **immediately know** that when your friend opens her box, she **must discover** a left-handed glove.

But now, apparently, some sort of **signal or information** must have traveled from your glove to hers, must it not?

If both gloves were **truly indeterminate** before you opened your box and looked inside, then **presumably as soon** as your **glove decided** to be(remember it is a 50-50 chance) a right-handed one, hers **must have become** left-handed, so that the two would be **guaranteed** to remain a pair.

That is the **rule** for these quantum-mechanical gloves.

Does this mean that your act of observing the glove in Chicago **instantaneously reduced** the indefiniteness of its partner in Philadelphia to a definite state of left-handedness?

It now occurs to you that there is **another possibility**.

How do you know that your friend did not get to Philadelphia **first** and open her box before you had a chance to open yours?

In that case, she evidently found a left-handed glove, which caused yours to be right-handed even before you looked inside your box.

So, **if there was** an instantaneous transmission of information, it might have **gone the other way**.

Your friend's act of opening her box **determined** what sort of glove you would find and not the other way around.

Now you **realize** that the only way to find out which way the instantaneous transmission of information went, from your glove to hers or from hers to yours, is to **use your cellphone** and call Philadelphia and find out at what time she opened her box.

That cellphone call, however, travels **slower than light**.

Now you are really getting **confused**.

There **seems to have been** some kind of instantaneous communication between the two gloves, **but** you cannot tell which way it went, and **to find out** you have to resort to old-fashioned, slower-than-light means of communication, **which seems to spoil** any interesting tricks you might be able to figure out if there really had been an instantaneous glove to-glove signal.

If you think again of the strategy whereby your friend had to get on a plane to either London or Paris, depending on which glove she found in her box, **then you realize** you are no more able than before to influence her choice by your action in Chicago.

The rules of the game are such that you have a 50-50 chance of finding either a right-handed or a left-handed glove in your box, so even if you are sure that you have opened your box before she opened hers, and even if you think that opening your box sends an instantaneous signal to hers, causing her glove to be the partner of yours, **you will still have no control** over which glove you find.

It remains a **50-50 chance** whether she will end up in London or Paris.

You have no say in the matter!

So now you are even more confused.

You think there has been some sort of instantaneous transmission of information, **but you cannot tell** which way it went, and **you cannot seem to find** a way to communicate anything to your friend by means of this secret link between the gloves.

Perhaps you might even conclude at this point that it is a good thing that real gloves are not like this.

In that case you would be in **agreement with Einstein.**

It is true that gloves **do not behave** this way, but according to quantum theory, **as we shall see**, electrons, photons and other elementary particles do!

These particles **have properties** which, apparently, lie in some **unresolved indeterminate (entangled) state until an observer comes along and does an experiment** that causes them to be one thing or the other(**collapses their state in some way**).

The observer **cannot know** in advance what the result of any particular measurement is going to yield; quantum theory **predicts only the probabilities** of possible results.

This **greatly offended** Einstein's view of what physics should be like.

Before quantum theory, it was **taken for granted** that when we measure something, we were gaining knowledge of a pre-existing state.

That is, gloves are **always either** right handed or left-handed, whether we are observing them or not, and when you discover what sort of glove you have, you are **simply taking note** of an independent fact about the world (objective reality).

Quantum theory says **otherwise**.

Some things are **not determined** except when they are **measured**, and it is **only by being measured** that they **take on** their specific values.

The gloves are **neither** right-handed nor left-handed **until we check**.

Einstein and his colleagues **actually devised** an experiment of this sort(not with gloves) as a way to show how absurd and unreasonable quantum theory really is.

They **hoped to convince** their physicist colleagues that something must be wrong with a theory that seemed to demand signals traveling faster than light.

Notwithstanding the genius of Einstein, in this case he was sadly **wrong**.

Nothing genuinely unacceptable is **actually happening** with the gloves.

The whole thing may **seem** very odd, and it may **seem** quite inescapable that some sort of instantaneous communication between gloves is essential for everything to work, but **in the end** it seems impossible to do anything with this communication.

We **will discuss** a real version of this experiment in detail later.