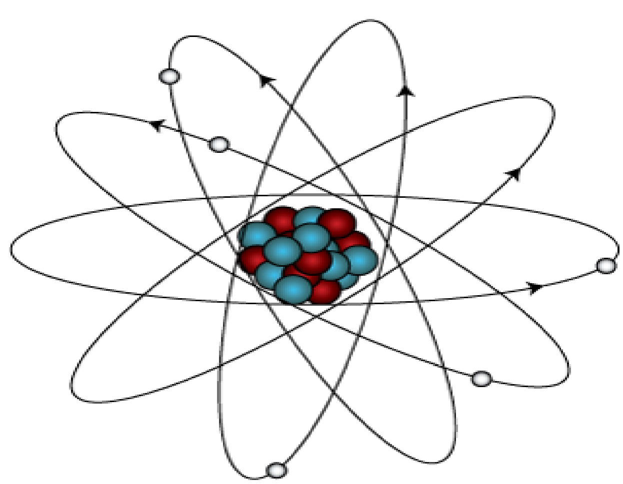
WHAT IS AN ELECTRON?

I like to do an odd thing with my chemistry students on the first day of class. I ask them to write down as many things as they know about an electron on a sheet of paper. Then we discuss them. All kinds of facts, some sophisticated, some not, come up:

Electrons are particles. They're waves. They're both particles and waves. They "orbit" the nuclei of atoms (picture →). They are very light. They "cause" electricity, and so on...

Then I walk around the room with a recycling bin and ask them all to crumple up the papers and toss them in. We start over, and I tell them this:

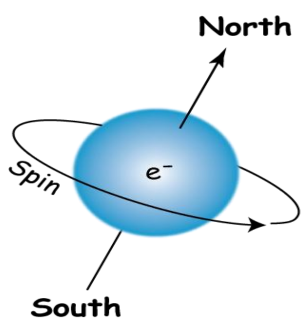


This diagram of an atom is inaccurate in many ways.

Key Experiments

A few key experiments, performed around the turn of the 20th century, began to show that matter at or below the size of atoms exhibited behavior that contradicted what was known so far about the physical world — the world of baseballs and Newton's laws of motion. Although there were many such experiments, I'll just go over a few here that I think tell a compelling story.

One of them, the **Stern-Gerlach experiment** is shown in the wide figure below. This is a very idealized version of the SG experiment. I've left out some experimental details, but rest assured that the essential experiment has been reproduced many thousands of times in various forms, all with the same result.



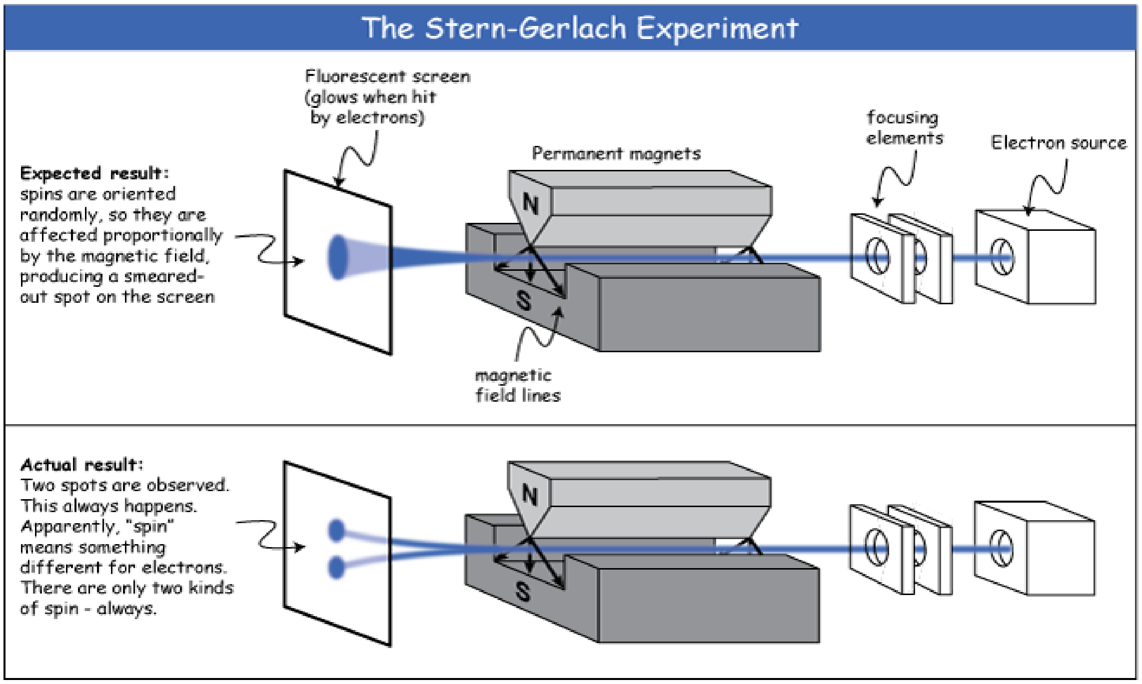
It works like this: Early on, scientists realized that electrons had magnetic properties because a beam of electrons could be deflected by placing a magnet nearby. Older televisions used of this principle.

It was also known that a spinning, charged object would exhibit magnetic properties, so the logical assumption was that electrons were spinning, charged particles — tiny little magnets with north and south poles.

Now in any group or **ensemble** of spinning charges, it would be reasonable to expect that all possible orientations of the magnetic field vector (← the straight arrow pointing north in the figure) would be present. That is, we would expect those arrows to be randomly oriented in space. Because of this, we'd expect to find a whole range of differences in how one electron would interact with an external magnetic field compared to any other. Some would be strongly repelled or attracted to one pole, others would be more weakly affected. There would be a **continuum** of interactions on a scale from weak to strong.

So the expected result of the SG experiment was that a beam of electrons that passed through a magnetic field would be "smeared out" when they hit some detector screen, a reflection of the wide range of effects "felt" by the magnetic field of the electron. Here is the experiment.

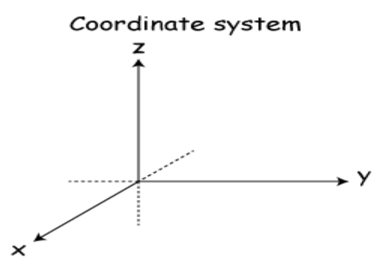
The expected result is shown in the top panel . . . and what *really* happens in the bottom:



What *actually* happens in the SG experiment is really stunning: The beam of electrons splits pretty cleanly into two separate beams, with nothing in the middle. These came to be called the "spin-up" and "spin-down" electrons (let's call these electrons **+z** and **-z** according to the coordinate system below). Apparently, when it comes to "spin" (which I put in quotes because it's now understood not to be like the spin of a spinning baseball), electrons come in only two "orientations", with nothing in between.

Even stranger results ...

And there are some even stranger results. Consider the following three scenarios, illustrated in a kind of shorthand in the wide figure below. Each set of magnets has been replaced by a box to simplify the diagram. In the first scenario, we follow the original SG apparatus (the one above) by another set of magnets oriented in the same way, but we only capture *one* of the split beams, the **+z**, and we block the other. As we might expect, the beam is simply further deflected in the same direction - no big surprise there. We had previously "filtered" the beam, now we expect it to pass through another filter in the same way.

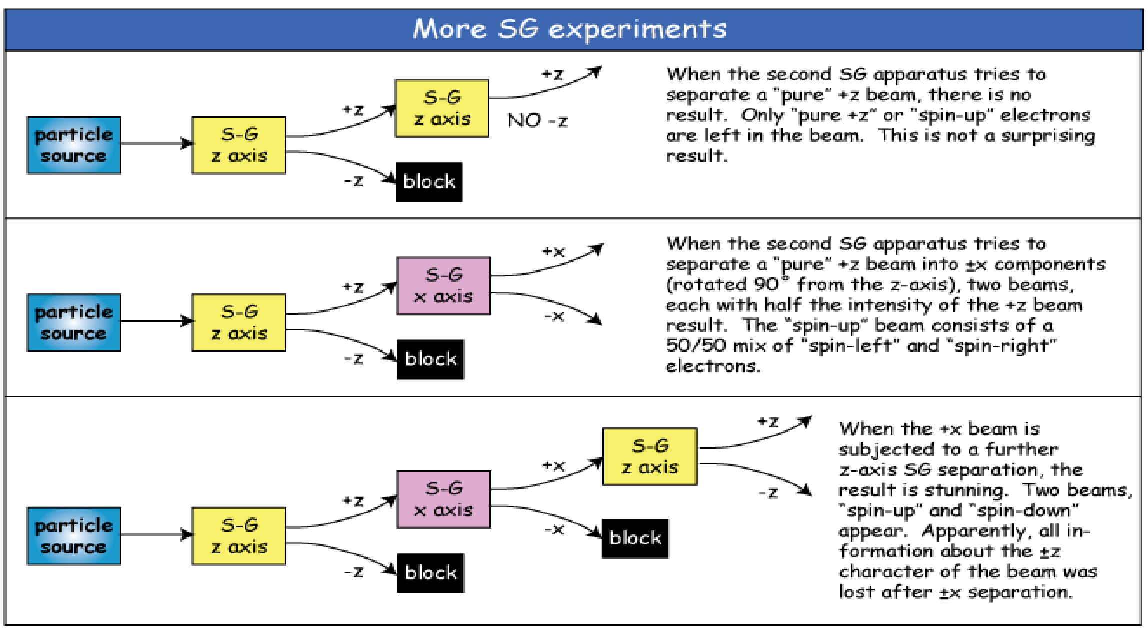


Use this coordinate system to interpret the SG experiments

In the second experiment, we do the same thing, but this time we rotate the second set of magnets 90˚ around the electron-beam axis (the y-axis in the coordinate system at right). The first experiment separated the beam into **±z** components. This second experiment seeks to separate *one* of those beams (**+z**) into ±x beams. The result: This time the +z beam is split cleanly into two beams, **+x** and **-x**.

Somehow, there is, embedded in one kind of spin along the z-direction, two kinds of spin along the x-direction.

Finally, we put a *third* set of SG magnets, acting in the z-direction, around one of the ±x beams from the previous experiment, blocking the other. The result: Two beams, ±z ! Apparently, upon going through the second set of magnets, all of the spin-up/spin-down (±z) identity of the beam was lost! Baseballs just don't behave like that.



What we've learned

We have learned that one property of electrons, which for historical reasons we call "spin", is **quantized**. That is, it can take on only one of two **discrete** values.

Whether we call those "up", "down", "left" or "right", or "**±z**" is just our naming. There are only two and there's never a "middle" spin of any kind.

We've also learned that spin is somehow affected by what kind of experiment or sorting was done before. When we pre-filter in one way, then filter in another, we lose all "memory" of the first filtering, strange behavior indeed.

Source: http://www.drcruzan.com/Chemistry_Electrons.html