BOTH SIDES NOW

It is only slightly overstating the case to say that physics is the study of symmetry.

Philip Anderson (1972)

At the beginning of time, when temperatures were incredibly hot, our universe must have been perfectly symmetrical.

Michio Kaku (1995)

Physicists are happy in the belief that Nature in its fundamental workings is essentially simple.

Roman Jackiw (1998)

Without invoking the power of symmetries, we'd be stuck at square one.

Brian Greene (2004)

Today he's here. He walks in with his fancy coffee. I don't wait for the caffeine to wake him up. Symmetry is a familiar concept. Symmetry is beauty. It is easy. So I show him this:

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It has two mirror symmetries—horizontal and vertical. And a rotation symmetry I show him: Turn it by 180°, it remains the same. In 3-D it has two more. A symmetry's a change that changes nothing. As this shows, one thing can have several symmetries.

A symmetry can be 'broken,' as they say. I select my figure and hit Ctrl-I. It looks like this:

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Both the mirror symmetries are broken. But it is still symmetric in rotation. I print it up so he can see. With the page flat on my desk I turn it a half circle. It looks the same. I tell him this is a *Symmetry Operation.*

Why am I making a big deal out of something that's so simple? Well, Anderson has answered; so has Greene. Yau goes even further, saying, 'In the end, the search for a simple, all-encompassing theory of nature amounts, in essence, to the search for the symmetry of the universe.'

Symmetry is the most potent tool for physics theorists today. Almost all the laws of physics involve symmetries. That is to say, in physics many properties turn out to be the same after certain operations. Or, even more interesting, not the same. As Carroll speculates in *Through the Looking Glass*, the universe does *not* have mirror symmetry. It's not the same when left and right are switched. Carroll has his Alice say to Kitty: 'Perhaps Looking-glass milk isn't good to drink.' Turns out, I tell Frank, it's not. He looks surprised so I repeat her mantra: Check it out. Then there's the neutrino. It's a sub-atomic particle. Every second billions of them zip through me—and right through the planet—all with no effect. The odd thing is that every one of them's left-handed. This time he turns to his computer; I don't need to say another word.

While he checks I work up notes for him on language. It sounds arcane but isn't all that hard. First, a *Symmetry Group* is just a collection of Symmetry Operations—a set of ways to change something that end up leaving it the same. The arcane bit is: They have strange names.

For example: $U(1)$ is the symmetry of rotating a circle:

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Simply, turning it leaves it unchanged:

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No matter how it turns it stays the same. The collection of all possible rotations is the $U(1)$ group. Why does he need to know this? Well, groups like this are what the forces of the universe are all about. The $U(1)$ group describes the electromagnetic force. $SU(2)$ describes the force that controls radioactivity. It's called 'weak.' $SU(3)$ describes the force that holds protons and neutrons together. Without it there would be no atoms and so no detectives. Luckily it's strong.

These symmetries *are* found in the universe today. And in the latter 1900s physicists find their three forces started out as one when the Big Bang began. This can be expressed by 'multiplying' the three symmetries, like this: $SU(3) \times SU(2) \times U(1)$. Today this is the magic incantation. In some papers it's on almost every second page I turn. Most profoundly it's the basis for the Standard Model—the master list of all the particles that physicists can find or make. It's why Oerter calls this list an unsung triumph.

He seems unusually patient. Perhaps because symmetry is something he can see. It's practical. That's good because I think it is important. It looks like the Beginning must have been symmetrical, though some of its symmetries are broken now. This needn't bother him. It bears a simple message: The way it is is not the way it was. He says little. He's still not sure what $SU(3) \times SU(2) \times U(1)$ is. I could be brutal and say check it out. He'd get hits. Like hundreds. He wouldn't understand them. He'd be confused. I think he thinks whatever it might be, it might be there at the Beginning. It's all he really needs to know.