Reflections

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". . . Not Even Wrong"

My favorite scientific putdown—one that I often use myself, in various contexts not necessarily scientific—was the work of the Austrian-born theoretical physicist Wolfgang Pauli (1900-1958), a Nobel Prize winner with a wicked and widely feared sense of humor. Pauli had a particular loathing for sloppy scientific thinking. His own thinking was coolly precise. Pauli was a severe critic of badly done work, a perfectionist who was able to put his finger immediately on a flaw in a theory's chain of reasoning and pronounce it, scathingly, as *ganz falsch,* "totally wrong."

But I would give Pauli's Nobel Prize citation a special footnote for his even more devastating response at one of those times when a fellow physicist showed him the paper of a colleague on which he wanted Pauli's opinion. Pauli read through the paper and said, looking up disdainfully, *Das is nicht nur nicht richtig, es ist nicht einmal falsch:* "Not only isn't this right, it isn't even wrong."

What Pauli meant by that was the other physicist's theory was based on ideas so far from acceptable scientific reasoning that they could neither be proven nor disproven: there was no way to evaluate them at all. The essence of science is the testing of hypotheses. If a concept can't be tested against current scientific knowledge because its basic assumptions are located so far from anything that anyone considers to be scientific, then it can't be proven or disproven, and so is scientifically worthless, however elegant it might be mathematically.

Pauli himself was not unwilling to stake his reputation on bold theoretical concepts that may have seemed "not even wrong" to some of his fellow physicists. There was, for example, his solution to the problem of conservation of angular momentum.

This was a double puzzle. One part of it was the question of beta decay. A neutron that is separated from the atomic nucleus will, in about 18 minutes, decay into a proton and an electron by emitting a beta particle. But the neutron before decay is some 1.5 electron masses heavier than the proton and electron it decays into. In terms of energy, this is some 780,000 electron volts. Where does the missing mass (or energy) go? If it just disappears, the law of conservation of energy is in error—a frightening thought to a scientist.

There was also the issue of missing spin. All known atomic particles have been found to spin like tops. The amount of the spin can be measured, and a unit of spin established. The math shows that in any nuclear reaction, spin—like matter, energy, or electrical charge—can neither be lost nor created. This is known as the law of angular momentum, another term for "spin." But in beta decay the breakdown of a neutron, with a spin of 1/2, produces a proton and an electron, *each* with a spin of 1/2. An extra spin of 1/2 has been created, seemingly. Or, if the proton and electron have opposite spins that balance out, half a unit of spin has been lost. Either way, the law of conservation of angular momentum seems to be violated.

It was Pauli, in 1933, who saved both conservation laws, that of energy and that of angular momentum, by something that looked very much like cheating. He invented a particle that no one had ever seen. It had no electric charge, nor even any mass while at rest. But it had a spin of 1/2. During beta decay, Pauli said, this ghostly particle is emitted by the neutron along with the beta particle. The missing 780,000 electron votes of energy are carried off, said Pauli, by his particle. And its spin of 1/2 cancels out the spin of one of the other particles, leaving a total spin of 1/2, the same that the neutron had had originally.

It was a very pretty solution. The Italian physicist Enrico Fermi dubbed the new particle the *neutrino,* meaning "little neutral one." The only problem was that there was no experimental evidence that neutrinos really existed. And how could you detect a particle that had no charge and no mass? For a long time it seemed as though Pauli's neutrino fell into his own "not even wrong" class—an idea that could neither be proven nor disproven, but remained simply hypothetical, a convenient mathematical construct that permitted a plausible workaround for a nasty problem but lacked any verifiable reality.

In 1956, though, two American physicists, Frederick Reines and Clyde Cowan, built a neutrino detector out of some six-foot-long tanks of water into which atomic particles from the Savannah River nuclear reactor were discharged. If neutrinos existed, they would stream into the tank and some would occasionally be captured by protons, turning each proton into a neutron and a positron (the positively charged equivalent of an electron). It was the precise reverse of beta decay. Each collision would cause flashes of light, which could be measured by electronic recorders. Reines and Cowan counted the flashes for 1,371 hours and found that they occurred at predictable intervals—which had to signify the emission of a neutrino. Pauli's theory was validated after twenty-three years. When Pauli was told of the experimental result he sent this telegram by way of reply: "Thanks for message. Everything comes to him who knows how to wait. Pauli."

More recently, the Columbia University mathematician Peter Woit has attacked one of the most hotly disputed ideas of modern physics, string theory, in a 2006 book called, appropriately enough, *Not Even Wrong.* String theory is a dazzlingly brilliant concept that I will not even pretend to understand, let alone explain here, because I am no physicist. A few sentences from its Wikipedia entry should give you a taste of it:

> String theory posits that the electrons and quarks within an atom are not 0-dimensional objects, but are made upu of 1-dimensional strings. These strings can oscillate, giving the observed particles their flavor, charge, mass, and spin. Among the modes of oscillation of the string is a massless spin-two state—a graviton. . . . Since string theory is widely believed to be mathematically consistent, many hope that it fully describes our universe, making it a theory of everything. . . . String theories also include objects other than strings, called branes. . . . The strings make closed loops unless they encounter D-branes, where they can open up into 1-dimensional lines. . . .

And so on and on and on. Peter Woit argues that there are no tests that can prove or disprove the existence of strings, branes, and all the rest, and so, however beautiful the theory and however eminent its proponents, it falls into the ". . . not even wrong" category.

Perhaps so. I am not the man to ask. The physicists themselves disagree. But I see where this elaborate hypothesis might cause uneasiness among the more conservative members of the profession.

My own favorite ". . . not even wrong" examples comes not from physics—as I say, I am no physicist—but from medieval scholarly disputation, a fertile area for such things. Consider the celebrated arguments over how many angels can dance on the head (or the point) of a pin. This seems to go back to Thomas Aquinas' *Summa Theologica* of 1270, which discussed such questions as "Can several angels be in the same place?" Aquinas did not in fact speak of angels on pinheads (or pinpoints), nor did any of his contemporaries or successors, and it may be that the whole topic was simply a scholastic training exercise. Nevertheless, the seventeenth-century theologian William Chillingworth refers in his *Religion of Protestants* to an argument, source unspecified, over "Whether a Million of Angels may not fit upon a needle's point?", and Richard Baxter, in a 1667 treatise on Christian belief, notes that some scholars have asserted "that Angels can contract their whole substance into one part of space. . . . Whereupon it is that the Schoolmen (again, unnamed) have questioned how many Angels may fit upon the point of a Needle." And it has, ever since, been pointed to as a prime example of the unanswerable theological question that grows out of a total absence of verifiable data that might allow proof or disproof.

A proper scientific answer to the question would require the researcher to measure the area of a standard pinhead and also to measure the feet of a sufficient number of angels to provide an average foot size for the entire angel population. Then one need merely divide the space available on one pinhead by the size of one average angelic footprint, see how much of the pinhead that would occupy, and multiply by two to get the space a single angel would take up, and then multiply again by the number of angels it would take to fill the entire pinhead. Thus if one normative angel would take up one tenth of a pinhead, it's easy enough to see that ten angels could dance (moving carefully, I suppose, in such a crowd) on that pinhead. If angels turned out to have smaller feet, more of them would fit on the same pinhead. It's just a matter of simple arithmetic.

An easy solution, yes, except for the problem of gathering data about the size of angels' feet. Since angels, like strings and branes, can't be rounded up in any useful quantity to be measured—in fact, their very existence is a matter of some doubt—we can't calculate the space that a single angel would consume on a pinhead, and so we can't go on to calculate how many angels *in toto* would fit on that pinhead. We could say, speculatively, that ten angels, or a thousand, or ten thousand, or an infinite number of angels might fit on one. But we have no way of proving it. It would just be a guess, and one guess would be as good as another. We can't even prove that angels exist at all—or disprove it, for that matter. So any calculations about angels and pinheads can't be accepted as correct, but neither can they be rejected as scientifically false. They aren't even wrong. There's no data to work with.

Peter Woit feels the same way about string theory. What the brilliant, acidulous Wolfgang Pauli would have said about that and other recent speculations in physics, I have no idea. For all I know, he would have embraced string theory in full fervor—or maybe not. (He isn't here to ask, so whatever guess I might make would be not even wrong.) His own neutrino theory seemed like a wild plunge into the unreal to many physicists, after all. But it turned out that neutrinos existed. And his 1945 Nobel Prize, for which he was nominated by Albert Einstein himself, was for his "decisive contribution through his discovery of a new law of Nature, the exclusion principle or Pauli principle," which involved spin theory and the whole structure of matter. Measuring the spin of an invisible particle might very well seem like measuring the number of dancing angels on a pinhead. But, again, Pauli was on to something real.

And so we should not think that his famous ". . . not even wrong" putdown meant that he was the enemy of all speculative thinking in physics. Far from it. But it is not only a funny line, it is an instructive reminder that the essence of the scientific method is proof. If an idea, however brilliantly it's argued, can't be proven (or disproven) because it's based on concepts that can't be tested in any rational manner, there's no way to incorporate it in the body of scientific knowledge. It can't be accepted as right; it can't be dismissed as wrong; it must simply be set aside, because it's . . . not even wrong.