Xiao-Gang Wen Academic Biography

Born in China in 1961, Xiao-Gang Wen received a BSc in physics from the University of Science and Technology of China in 1982. In his graduate work at Princeton University, Wen studied superstring theory under Edward Witten, a leader in the field, receiving a PhD in 1987. He later switched his research field to condensed matter physics while working at the Institute for Theoretical Physics, UC Santa Barbara (now the Kavli Institute).

“I prefer to work on totally new topics that expand the boundary of our knowledge of nature -- unexplored areas of physics that no one has touched before,” says Wen.

Immediately before joining Perimeter Institute, Wen was the Cecil and Ida Green Professor of Physics at MIT. He is a fellow of the American Physical Society, a Distinguished Moore Scholar at Caltech, and (since 2009) one of Perimeter’s own Distinguished Research Chairs.

The author of the textbook *Quantum Field Theory of Many-body Systems: From the Origin of Sound to an Origin of Light and Electrons*, Wen is widely recognized as one of the world’s leaders in condensed matter theory.

Xiao-Gang Wen: Research Overview

New States of Matter

New states of matter are the Holy Grails of condensed matter physics, and Xiao-Gang Wen has done much to advance the quest for them. It was his introduction of the notion of topological order (in 1989) that enabled physicists to describe a whole new class of matter – topological matter – which exhibits quantum entanglement properties at macroscopic scales. This breakthrough opened up new research directions, and topological matter is now one of the most active research areas in condensed matter physics.

Wen himself has made major discoveries in the new field of topological order that he created. Notably, he found (in 1990) that topological matter has “protected boundary excitations”. These enable topological matter to have a perfect conducting boundary despite an insulating interior. In other words, topological matter acts like a plastic cable covered with a layer of metal, even though the material is actually the same throughout. Such unique properties may make topological matter useful in building special electronic devices. The topological insulator is a popular example of such topological matter; protected boundary excitations played a key role in its development.

But topological order has implications well beyond material science. It opens new research directions in quantum information science, high energy physics, and even modern mathematics. It is rapidly becoming a new cornerstone in the expansion of many-body physics.

Wen, for his part, thinks big: he has turned his expertise in topological order toward creating new models of the universe itself.

Real Versus Emergent

One of the most fruitful questions in modern physics is, “what is fundamental, and what is emergent?” Emergence is an important and powerful idea in physics, one vital to tackling such everyday questions as why solids have fixed shapes but liquids can flow freely, why some materials conduct electricity and some insulate, why metals are shiny, and more. Each of these questions concerns a system made up of a large number of particles. A single drop of water, for instance, will have more than 10^{20} water molecules, each with the same well-defined properties. Put many water molecules together in a system, and those fundamental properties will cause different characteristics to be observed in different conditions: what we see is a glass of water or an ice cube or puff of steam. The properties of the system that do not belong to its constituent parts are said to be emergent.

In the late 1990s, condensed matter physics was deeply concerned with a particularly puzzling emergent property: certain semiconductors were behaving as if the particles inside them had a fraction of an electron’s charge. This was shocking, because, like the speed of light or Planck’s constant, the charge of the electron had long been one of the fixed points of the disorienting quantum universe. Every system in the universe carried whole multiples of a single electron’s charge.

The strange behavior of these semiconductors was known as the fractional quantum Hall effect (FQHE), and some might regard this as evidence that electrons are not elementary particles with no internal structure, but are in fact made of smaller parts, each with a fraction of a single electron’s charge. However, it soon became clear that the fractional charge was an emergent property: the electrons were congregating in a way that gave the illusion of particles with fractional charges.

Wen’s work in this area, the co-discovery (in 1991) of a special class of FQH states, called non-Abelian FQH states, was a breakthrough. Emergent particles in non-Abelian states have the amazing and exotic property that they can change their types in a precise way as they braid around each other, without even touching! These exotic new particles could have major applications in topological quantum computing – a type of quantum computing that is naturally fault-tolerant.

But Wen went further. The exotic fractionally-charged particles in FQHE systems were not real: they were an emergent property of the material. What if electrons themselves were not real, but emergent?

The Universe as a Bowl of Noodles

Wen and his collaborator Michael Levin (now at Maryland University), developed a model in which they picture electrons as the ends of long “strings” of qubits – qubits being the simplest and most fundamental object in quantum theory. As the qubits fluctuate, these strings are free to move like noodles in a soup and weave together into huge “string-nets”.

The researchers applied advanced modern mathematics to study their string nets to see if they could give rise to both the exotic fractionally charged quasiparticles of FQHE and the long-thought fundamental electrons. The string nets did. Not only that, but other particles began popping up as the ends of differently woven string nets, such as quarks and leptons.

There were more surprises: when the net of strings vibrated, it produced a wave, and that wave behaved according to Maxwell’s equations. A bedrock of physics since the 1860s, Maxwell’s equations are the basic equations for explaining and unifying light, electricity, and magnetism. The string nets were producing, as emergent properties, both matter and light. And more is coming: in addition to the photons that carry the electric and magnetic force, waves in differently woven string nets lead to other force-carrying particles such as gluons and W and Z bosons.

Matter, light: to a physicist, that's almost everything. Could the entire universe be modeled as a bowl of noodles? "Suddenly we realized, maybe the vacuum of our whole universe is a particular topological matter – a string-net liquid," says Wen. "It would provide a unified explanation of how both light and matter arise."

If that's true, then what we today call elementary particles are not the fundamental building blocks of matter. Instead, they emerge from simple qubits that form the non-empty vacuum of spacetime.

At Perimeter, Wen plans to push this startling research further. He plans to build a research team, and collaborate with Perimeter experts already in place. "My research is very interdisciplinary, and relies on ideas from condensed matter physics, quantum information science, high energy physics, and cosmology," he says. "All in all, it fits Perimeter's philosophy and research model very well."