Bringing ideas to life through experimental physics

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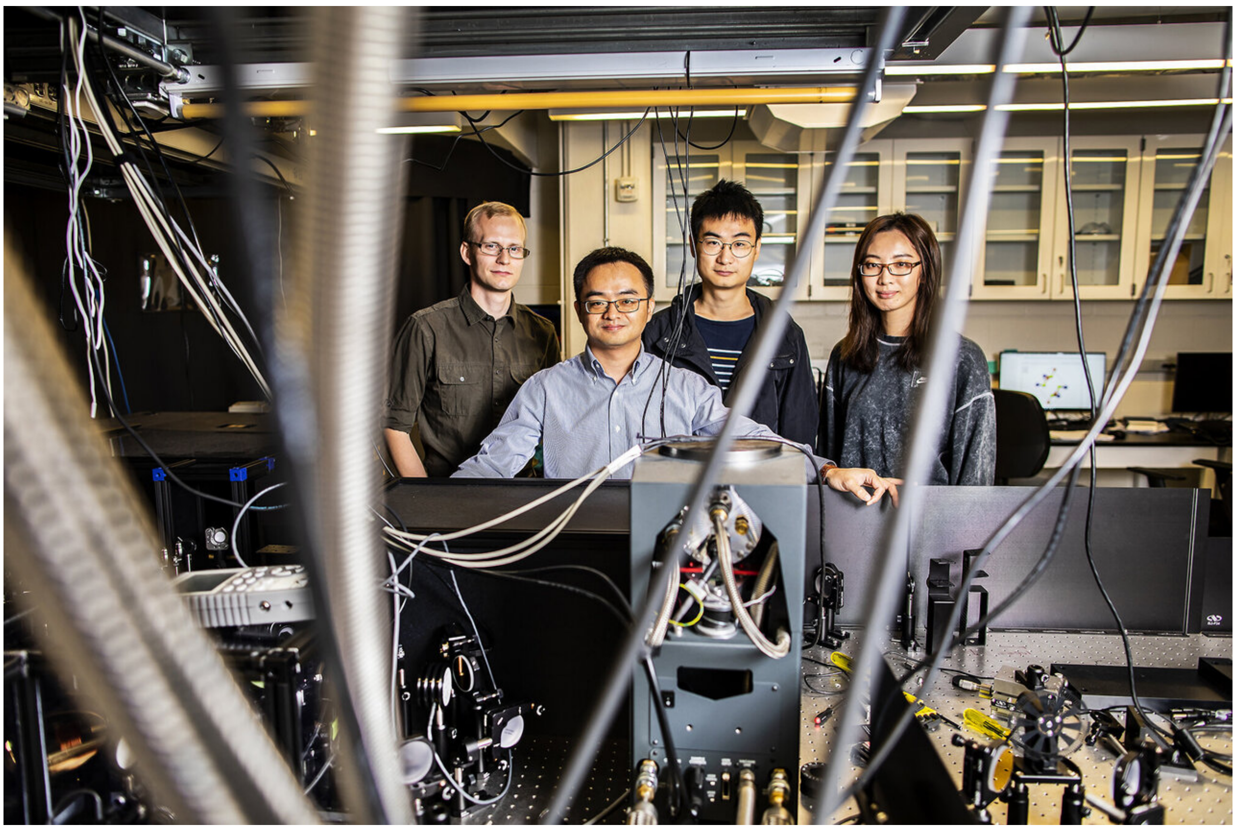

The goals of Liang Wu's lab are to better understand the physics of quantum materials. Their fundamental research in the field of optics can help create the next generation of everything from quantum computers to solar cells. Credit: University of Pennsylvania

Even the most brilliant scientific ideas need data. Just this year, the firstever image of a black hole finally provided the evidence needed to support Einstein's 100-year-old theories.

Quantum materials are no stranger to this need. The Breakthrough Prize-winning theory proposed by Penn's Charles Kane and Eugene Mele on topological insulators, materials that act as insulators on the inside and conductors on the surface, became the foundation for a field of physics research that hopes to help engineers develop more efficient optoelectronic devices or quantum computers.

Liang Wu and his lab are generating data to help bring these and other ideas in the field of quantum materials to life. As an assistant professor in the Physics & Astronomy Department of the School of Arts and Scienes at Penn, Wu is focused on optical experiments that can help scientists, both on the theory and experimental sides, understand this class of materials while, on occasion, making new discoveries in the process.

While Wu says that much of the work in the lab is more "routine," verifying predictions made by theorists, but that there are times when an experiment finds something unexpected that wasn't predicted by a theory. In both instances, there is a considerable collaboration between both types of researcher groups, between running experiments, making sense of results, and planning additional experiments that can help confirm new hypotheses.

The Wu lab conducts optics experiments to study the ways that light interacts with quantum materials. The group is studying effects in the nonlinear response regime, where the relationship between input and output is more complicated to model. "Optics is one of the fields where we have a good understanding of linear effects, but what's more interesting are often nonlinear responses. It's hard to deal with but extremely useful," says graduate student Jon Stensberg.

Stensberg and graduate student Xingyue Han work on terahertz signals, sub-millimeter waves that aren't visible to the naked eye. Han, who did her undergraduate thesis with Wu and helped build two custom terahertz setups, uses magnetic topological materials to study interactions between matter and light. This work could eventually lead to more efficient terahertz emitters and memory devices that could perform 1,000 times faster than existing platforms.

Stensberg is looking at the interactions between topological insulators and superconductors to help make more stable quantum computing devices. Current quantum information storage devices are very fragile, so it's easy for data to become lost or scrambled. Through his fundamental research, Stensberg hopes to find a material that can store quantum states in topological phases for more long-term stability.

Another graduate student, Zhuoliang Ni, has built three different nonlinear optical setups and is exploring the fundamental properties of topological materials that can efficiently convert light into electrical current. One goal is to find optical electronic materials that can be turned on and off more quickly, which would make them more energy efficient. Preliminary work has found some possible contenders, and Wu and Ni are now working with theorists to develop new models to understand the data they are collecting.

Joe Qiu, a program manager at the Army Research Office which funds Wu's work, says that this research has the potential to create devices that can help people better sense their environment, which could be especially useful for soldier situational awareness.

"Understanding the fundamental properties of magnetic Weyl semimetals and multifold Fermions semimetals will lay a foundation for new technological paradigms for applications including spintronic memory devices for information processing, energy efficient electronics, and terahertz sources," Qiu says.

Much of the group's time is spent aligning and running optical experiments, work that Wu says requires a lot of time and patience "It's a big jump," he says about going from understanding a theory to setting up and running experiments. "In the beginning it's slow; it takes time."

Wu's students say that despite the challenges of the work, setting up and running experiments is a great learning opportunity. "I learned much more from the process," says Han. "For example, in class I can, say, apply a magnetic field and observe a particle, but here first you have to apply a magnetic field, and that's always very complicated."

Wu started his academic career as an environmental engineering major who was keen on solving problems. Wanting to dive more deeply into fundamental science, he changed his study to physics so he could use math to solve problems. "Physics is something where I can use math a lot, something that in certain cases might lead to applications," he says.

Stensberg's research on the interactions between topological insulators and superconductors is motivated by quantum computing applications. He says that the opportunity to work on challenging optics experiments is incredibly rewarding. "We have to understand how all of it works and how it all comes together," he says about the optical tables they work with in the lab.

His graduate students share similar passions for physics and were attracted to the lab because of the work's connection between theory and experiment. Stensberg met Wu when the lab was lined by empty cabinets and adds that the positive ambiance of the department attracted him to Penn. "The people here seemed very genuinely happy," he says. "They like working with the people here, they like the city, and the work was really interesting."

Wu was recently awarded the 2019 William McMillan Award for his contributions to condensed matter physics. A few years after topological insulators were first theorized, Wu began to look at their electrodynamics. With a bit of luck and a lot of effort, he was able to identify topological materials called Weyl semimetals, a material with large optical non-linearity where photo current could be generated very efficiently. His "too good to be true" results proved incredibly fruitful.

In the next few years, Wu hopes to see the group keep its focus on fundamental topological materials research, although he admits that it's difficult to know what the future holds for such a young field. "When I started graduate school, my graduate advisor told me that this is a new field, there are lots of opportunities, but it might also die in two years. At the time I didn't know much about experiments, so I just kept working, and I was lucky that this field really exploded," says Wu.

Inside the lab, their research is indeed explosive, in an exciting but nonhazardous way, his students emphasize. Outfitted with numerous lasers, lenses, magnets, and measurement devices, their basement lab is, quite literally, buzzing.

"My research is more fundamental, but I really hope that one day they could be useful for applications," he says. "We're building and learning, and I think that the most exciting part of doing experiments is discovering something new."

Provided by University of Pennsylvania