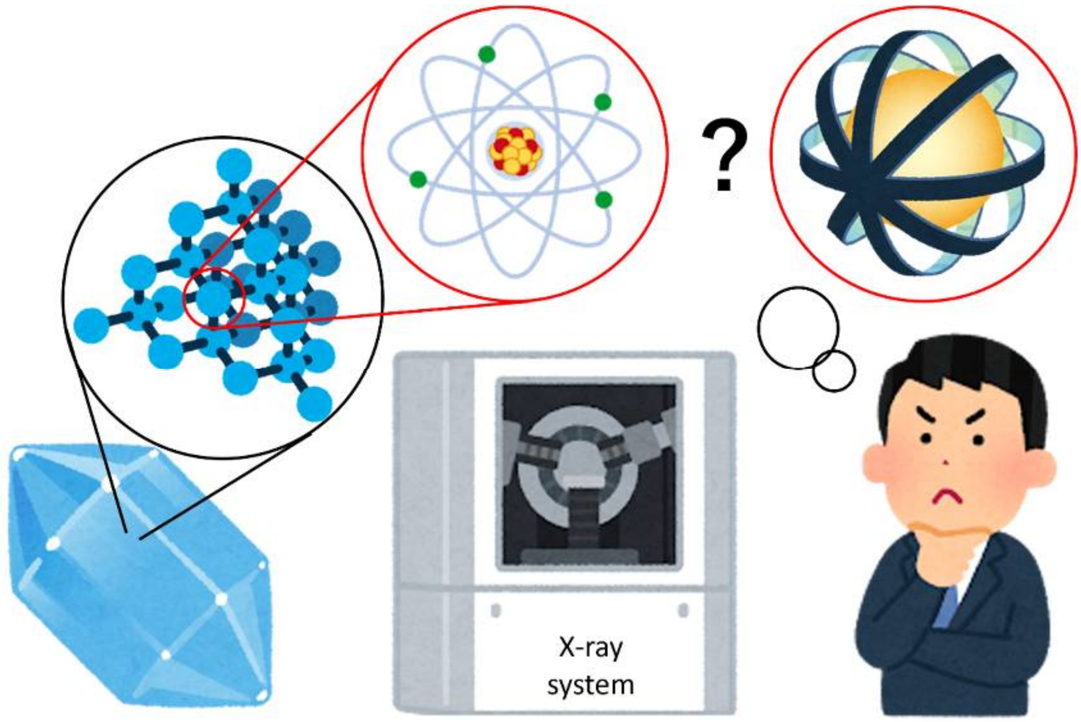
Shungo Aoyagi, M2 student at department of applied physics

Title: The Hidden Shapes of Matter: My Journey into Electron Worlds



I'm currently doing research on what's happening inside solid materials. Let's break down what makes up a solid. First, solids are made of different kinds of atoms - like hydrogen and oxygen in ice, or iron in magnets. No matter what type of atom, they all have a nucleus and electrons, and when these electrons move, they create electricity or magnetic forces in the solid.

Even though all materials are made from the same basic parts, different materials behave differently because the electrons inside them are arranged in completely different ways. Scientists have already shown using various methods that electron states differ between materials, but only very recently have we been able to clearly see how electrons are actually spread out in space.

My research focuses on making these electron states visible. I study different materials to see how their electrons are distributed and try to find out why these differences happen. So far, our research has shown that even when atoms are arranged in the same pattern, the way electrons spread out can be completely different.

How can we see the state of electrons? There are many ways to observe tiny structures, like using microscopes, but what we're trying to study here is the structure at the 0.0000000001 meter level, which is way too small for regular microscopes to see.

That's why we use X-rays. In medical applications of X-rays, their ability to pass through the body is used, but a different property is needed to observe fine structures — scattering, which occurs when X-rays hit electrons. When we add up all the X-rays that have hit different electrons, the combined waves create different interference patterns depending on whether the waves strengthen each other or cancel each other out. By analyzing these interference patterns, we can figure out how the electrons are spread out.

What I find interesting about this research is that we can directly see the state of electrons inside materials through experiments. Almost everything we touch daily - computers, pencils, books - is made of solids. Aren't you curious about what these solids look like at their tiniest level?

Solids can be grouped in many ways - those that conduct electricity and those that don't, transparent ones and opaque ones. Modern physics explains most of these properties, but do we really know what shape the electrons take that cause these effects? The answer is no. If we could understand this, we might be able to predict things like, "If we create electrons distributed in this particular shape, this amazing phenomenon should happen on a large scale," and even design new materials.

In most physics research dealing with solids, the internal electron states are only studied using computer simulations. This method, called first-principles calculation, is widely used because it needs almost no experimental parameters. However, there are still some effects that can't be included in these simulations, so we can't predict everything just with calculations. On the other hand, the direct observation method I use is an actual experiment, not a simulation, so it doesn't miss these "uncaptured effects." Being able to directly observe the state of materials is what makes this research so fascinating.

Another exciting part of this research is that unexpected things keep happening. Since these methods for directly observing electron distributions were only developed very recently, we barely know what distributions look like in different materials. When we observe them, we frequently find surprises - like seeing completely different electron distributions just because there's one extra electron, even when the atoms are arranged the same way, or finding distributions in completely unexpected shapes. The joy of figuring out the physics behind these discoveries and building a logical story to explain them is immeasurable.

If I could give advice to my 12-year-old self, it would be to keep your curiosity alive. The field of solid-state physics covers a lot of ground. That's because almost everything around us is made of solids, and they show an incredible variety of behaviors. The technique I'm working with has only recently been established, and while in theory we can observe any material as long as we can make a nice crystal of it, many material systems remain unexplored. What you need in this situation is curiosity about what interests you personally and what you want to investigate, plus the initiative to actually do it. In other words, curiosity is the foundation of all research.

In contrast, when I was around 12, I was pretty caught up in immediate things like schoolwork and club activities, and I was spending less time exploring different interests out of pure curiosity. While this was partly a natural narrowing of interests, and those activities definitely helped shape who I am today, I often think that if I had kept exploring a wider range of topics, I would have developed a broader perspective and come up with more diverse ideas.

How can you develop curiosity? I think it's about not ignoring those little questions that catch your attention. When you think, "What is this?" or "How does this work?", instead of forgetting about it and moving on, take a moment to think more deeply or look it up right away. This gradually makes it easier to explore all kinds of ideas.

When you consider that this kind of thinking also helps you get better at various activities, including physical ones, having broad curiosity is important not just for scientific research — for me, visualizing electron states —, but for many areas of life.

I used ChatGPT to improve my English and fix grammatical errors. All illustrations used in the figure were sourced from “いらすとや”.