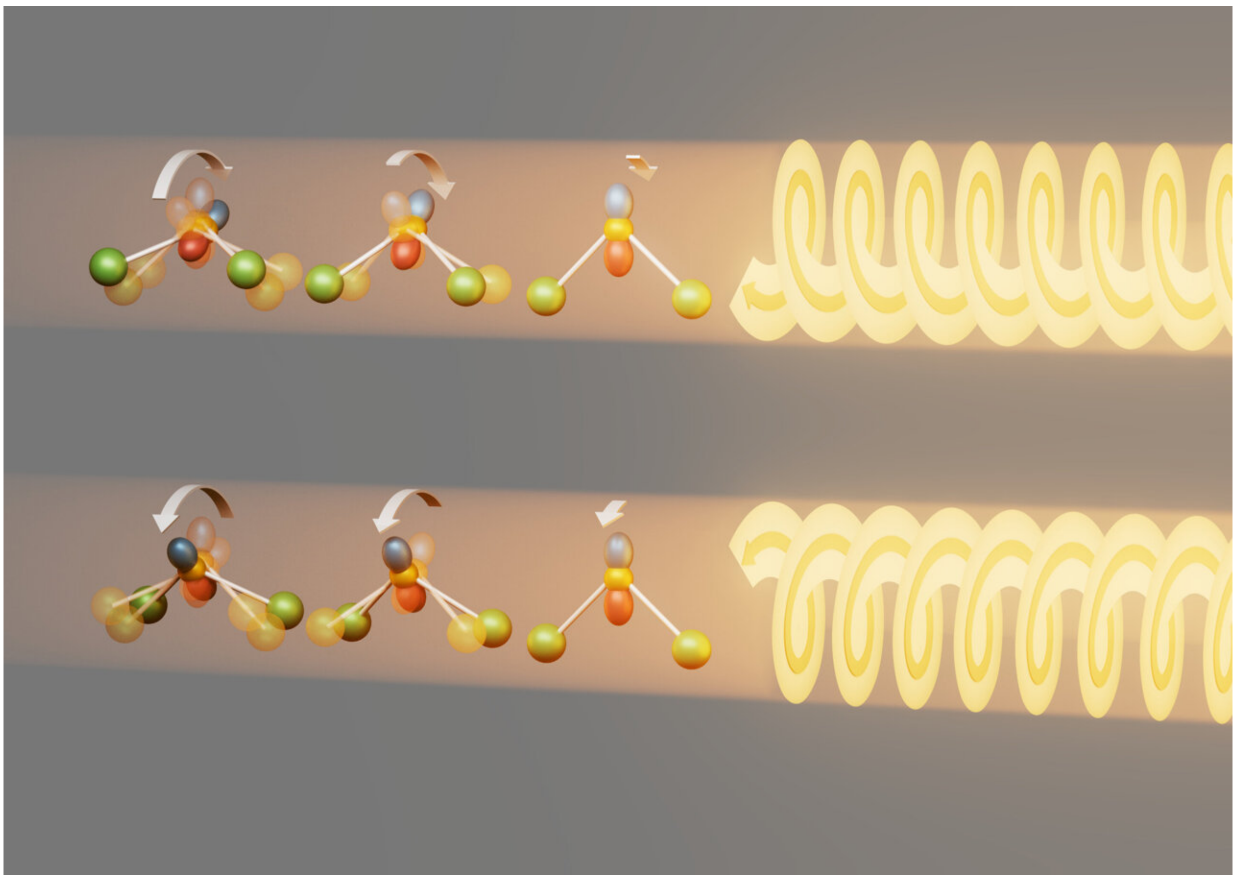
Phonons can be chiral: Study claims to settle the debate

June 9 2023, by Miriam Arrell



To prove the existence of chiral phonons, researchers used resonant inelastic X-rays scattering (RIXS). Circularly polarized light shines on quartz. The angular momentum of the photons is transferred to a crystal, causing a revolution in this case of anions (orange spheres with p orbitals) relative to their neighboring cations (green spheres). Credit: Paul Scherrer Institute / Hiroki Ueda and Mahir Dzambegovic

Findings published in *Nature* settle the dispute: phonons can be chiral. This fundamental concept, discovered using circular X-ray light, sees phonons twisting like a corkscrew through quartz.

Throughout nature, at all scales, you can find examples of chirality—or handedness. Imagine trying to eat a sandwich with two hands that were not enantiomers—non-superimposable mirror images—of each other. Consider the pharmacological disasters caused by administering the wrong drug enantiomer or, at a subatomic scale, the importance of the concept of parity in particle physics. Now, thanks to a new study led by researchers at Paul Scherrer Institute PSI, we know that phonons can also possess this property.

A phonon is a quasiparticle that describes the collective vibrational excitations of the atoms in a crystal lattice; imagine it as the Irish Riverdance of the atoms. Physicists have predicted that if phonons can demonstrate chirality they could have important implications on the fundamental physical properties of materials. With the rapid rise in recent years of research into topological materials that exhibit curious electronic and magnetic surface properties, interest in chiral phonons has grown. Yet, experimental proof for their existence has remained elusive.

What makes phonons chiral is the steps of their dance. In the new study, the atomic vibrations dance a twist that moves forwards like a corkscrew. This corkscrew motion is one of the reasons there has been such a drive to discover the phenomenon. If phonons can revolve in this way, like the coil of wire that forms a solenoid, perhaps they could create a magnetic field in a material.

A new slant on the problem

It is this possibility that motivated the group of Urs Staub at PSI, who led the study. "It is because we are at the juncture between ultrafast X-ray science and materials research that we could approach the problem from a different angle," he says. The researchers are interested in manipulating chiral modes of materials using chiral light—light that is circularly polarized.

It was using such light that the researchers could make their proof. Using quartz, one of the best-known minerals whose atoms—silicon and oxygen—form a chiral structure, they showed how circularly polarized light coupled to chiral phonons. To do this, they used a technique known as resonant inelastic X-ray scattering (RIXS) at the Diamond Light Source in the UK. This was complemented with supporting theoretical descriptions of how the process would create and enable the detection of chiral phonons from groups at the ETH Zurich (Carl Romao and Nicola Spaldin) and MPI Dresden (Jeroen van den Brink).

'It doesn't usually work like this in science'

In their experiment, circularly polarized light shines on quartz. The photons of light possess angular momentum, which they transfer to the atomic lattice, launching the vibrations into their corkscrew motion. The direction that the phonons revolve depends on the intrinsic chirality of the quartz crystal. As the phonons revolve, they release energy in the form of scattered light, which can be detected.

Imagine standing on a roundabout and throwing a Frisbee. If you throw the Frisbee with the same direction of movement as the roundabout, you would expect it to whizz. Throw it the other way and it will spin less, as the angular momentum of the roundabout and the Frisbee will cancel out. In the same way, when the circularly polarized light twists the same way as the phonon it excites, the signal is enhanced, and chiral phonons could be detected.

A well-planned experiment, careful theoretical calculations, and then something strange happened: almost everything went according to plan. As soon as they analyzed the results, the difference in response as the chirality of the light flipped was undeniable.

"The results were convincing almost immediately, especially when we compared the difference with the other quartz enantiomers," remembers PSI scientist and publication first-author Hiroki Ueda. Sitting at his computer to analyze the data, Ueda was the first person to see the results: "I kept checking my analysis codes to make sure it was true." Staub emphasizes, "It's not normal! It doesn't usually work like this in science!"

During the quest for chiral phonons, there have been several false alarms. Will this settle the debate? "Yes, I think so, that's the beauty of this piece of work," believes Staub, whose opinion was shared by the reviewers at *Nature*. "Because it's simple, and beautiful and straightforward. It's obvious. It's so simple, it's obvious that this is the chiral motion."

More information: Hiroki Ueda et al, Chiral phonons in quartz probed by X-rays, *Nature* (2023). DOI: 10.1038/s41586-023-06016-5

Provided by Paul Scherrer Institute