TechAndComputer (Dec. 3, 2012) — When the dry lubricant, molybdenum disulfide, is stripped down to a single layer of atoms, a tightly bound quasi-particle composed of two electrons and a hole forms with unique spin and valley properties, researchers from Case Western Reserve University and colleagues discovered.

These charged quasi-particles, called negative trions, can be manipulated to change the light absorbed and emitted from this two-dimensional semi-conducting crystal, opening it to potential use in new solar cells and other electronic devices that are controlled by light or designed to control light.

The discovery also opens up new opportunities to study what physicists call "many-body interactions"--in this case, the interactions among the charged particles--and a new concept of electronics called valleytronics.

The research is published in this week's online edition of *Nature Materials*.

"What we saw was something like a negative hydrogen ion-a positive charge bound to two negative charges," said Jie Shan, an associate professor of physics at Case Western Reserve and senior author of the paper.

The trions formed in the molybdenum disulfide crystal when the researchers applied a bias voltage on the back gate of a device called field-effect transistor. This was done at 10 degrees Kelvin, or -441 Fahrenheit. The electrons introduced by the bias voltage were linked to electron-hole pairs generated by absorption of photons, resulting in negatively charged trions.

"The interactions between charged particles in three-dimensional bulk materials are usually screened by the presence of other charges in the material. Because this material has an atomic thickness, the interactions between the charges are much stronger than in the natural bulk material due the drastically reduced screening," Shan explained. "The quasi particles are stable. Adding energy comparable to or larger than that of room temperature to the monolayer is required to break away the extra negative charge."

Because the trions are charged, they can be controlled by a bias electric field, Shan said. "This is very basic science; it is early, but this may offer a unique opportunity to use controllable and directional transport of optical excitation in a material, which could be useful for applications such as photovoltaics and optoelectronics."

Shan worked with her graduate student, Kelinang He, and, from Columbia University, Kin Fai Mak, a postdoctoral researcher, Tony F. Heinz, professor of physics and electrical engineering, Gwan Hyoung Lee postdoctoral researcher and James Hone, professor of mechanical engineering. Changgu Lee, an assistant professor of mechanical engineering at Sungkyunkwan University also contributed to the research.

The discovery of the trions increases the potential that this material can be used for valleytronics, the researchers say. Earlier this year, Mak, He, Shan and Heinz, and other research groups found they could control what's known as valley polarization-essential to valleytronics--in a single layer of molybdenum disulfide.

Conventional electronics rely on the control of the charge through materials. Spintronics use the spin degree of freedom of the charge carriers. Valleytronics rely on another property.

Because of symmetry, crystals frequently have independent, degenerate valleys in their energy bands. This so-called "valley" (or momentum) degree of freedom has been proposed as something that could be manipulated for new classes of electronic devices.

Using polarized light, Shan and fellow researchers were able to nudge electrons into a desired valley.

"The trions also show some interesting valley properties," Shan said. "But their valley lifetime may be very different, because it involves the interaction of three particles."

The researchers are continuing to probe the properties in a series of experiments.

Story Source:

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Journal Reference:

1. Kin Fai Mak, Keliang He, Changgu Lee, Gwan Hyoung Lee, James Hone, Tony F. Heinz, Jie Shan. **Tightly bound trions in monolayer MoS2**. *Nature Materials*, 2012; DOI: 10.1038/nmat3505

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