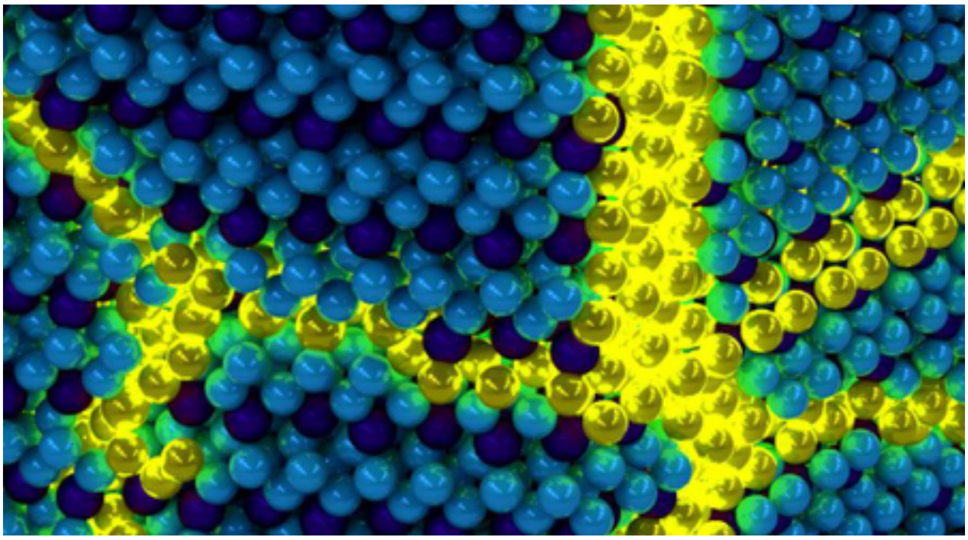
Azimuth

Excitonium


(https://physics.illinois.edu/news/article/24114)

In certain crystals you can knock an electron out of its favorite place and leave a **hole (https://en.wikipedia.org/wiki/Electron_hole)**: a place with a missing electron. Sometimes these holes can move around like particles. And naturally these holes attract electrons, since they are *places an electron would want to be*.

Since an electron and a hole attract each other, they can orbit each other. An orbiting electron-hole pair is a bit like a hydrogen atom, where an electron orbits a proton. All of this is quantum-mechanical, of course, so you should be imagining smeared-out wavefunctions, not little dots moving around. But imagine dots if it's easier.

An orbiting electron-hole pair is called an **exciton (https://en.wikipedia.org/wiki/Exciton)**, because while it acts like a particle in its own right, it's really just a special kind of 'excited' electron—an electron with extra energy, not in its lowest energy state where it wants to be.

An exciton usually doesn't last long: the orbiting electron and hole spiral towards each other, the electron finds the hole it's been seeking, and it settles down.

But excitons can last long enough to do interesting things. In 1978 the Russian physicist Abrikosov wrote a short and very creative paper in which he raised the possibility that *excitons could form a crystal in their own right!* He called this new state of matter **excitonium**.

In fact his reasoning was very simple.

Just as electrons have a mass, so do holes. That sounds odd, since a hole is just a vacant spot where an electron would like to be. But such a hole can move around. It has more energy when it moves faster, and it takes force to accelerate it—so it acts just like it has a mass! The precise mass of a hole depends on the nature of the substance we're dealing with.

Now imagine a substance with very heavy holes.

When a hole is much heavier than an electron, it will stand almost still when an electron orbits it. So, they form an exciton that's *very* similar to a hydrogen atom, where we have an electron orbiting a much heavier proton.

Hydrogen comes in different forms: gas, liquid, solid… and at extreme pressures, like in the core of Jupiter, hydrogen becomes *metallic*. So, we should expect that excitons can come in all these different forms too!

We should be able to create an exciton gas… an exciton liquid… an exciton solid…. and under the right circumstances, a *metallic crystal of excitons*. Abrikosov called this **metallic excitonium**.

People have been trying to create this stuff for a long time. Some claim to have succeeded. But a new paper claims to have found something else: a Bose–Einstein condensate of excitons:

• Anshul Kogar *et al*, Signatures of exciton condensation in a transition metal dichalcogenide, *Science (http://science.sciencemag.org/content/358/6368/1314)* (2017).

A lone electron acts like a fermion, so I guess a hole does do, and if so that means an exciton acts approximately like a boson. When it's cold, a gas of bosons will 'condense', with a significant fraction of them settling into the lowest energy states available. I guess excitons have been seen to do this!

There's a pretty good simplified explanation at the University of Illinois website:

• Siv Schwink, Physicists excited by discovery of new form of matter, excitonium (https://physics.illinois.edu/news/article/24114), 7 December 2017.

However, the picture on this page, which I used above, shows domain walls moving through crystallized excitonium. I think that's different than a Bose-Einstein condensate!

I urge you to look at Abrikosov's paper. It's short and beautiful:

• Alexei Alexeyevich Abrikosov, A possible mechanism of high temperature superconductivity (http://www.jetpletters.ac.ru/ps/1547/article_23682.pdf), *Journal of the Less Common Metals* **62** (1978), 451–455.

(Cool journal title. Is there a journal of the *more* common metals?)

In this paper, Abrikoskov points out that previous authors had the idea of metallic excitonium. Maybe his new idea was that this might be a superconductor—and that this might explain high-temperature superconductivity. The reason for his guess is that metallic hydrogen, too, is widely suspected to be a superconductor.

Later, Abrikosov won the Nobel prize (https://www.nobelprize.org/nobel_prizes/physics/laureates/2003/abrikosov-bio.html) for some other ideas about superconductors. I think I should read more of his papers. He seems like one of those physicists with great intuitions.

Puzzle 1. If a crystal of excitons conducts electricity, what is actually going on? That is, which electrons are moving around, and how?

This is a fun puzzle because an exciton crystal is a kind of *abstract* crystal created by the motion of electrons in another, ordinary, crystal. And that leads me to another puzzle, that I don't know the answer to:

Puzzle 2. Is it possible to create a hole in excitonium? If so, it possible to create an exciton in excitonium? If so, is it possible to create **meta-excitonium**: an crystal of excitons in excitonium?

This entry was posted on Sunday, December 10th, 2017 at 2:30 am and is filed under physics. You can follow any responses to this entry through the RSS 2.0 feed. You can leave a response, or trackback from your own site.

5 Responses to *Excitonium*

allenknutson says:
10 December, 2017 at 5:05 am
What sort of material is it, that a hole could be more massive than an electron?

Also, I vaguely understand why an electron doesn't merge with a proton. But wouldn't electrons love to fall into holes? How long-lived are these states of excitonium suppose to be?

Reply
Kram Einsnulldreizwei says:
10 December, 2017 at 6:43 am
An Excitronium hole? Interesting.
I suspect that this is totally possible, somehow. Though what would that mean? Are we talking that an electron-hole-pair, a single excitron, is gone missing? In that case, the resulting structure would remain neutral, right? (Though the missing pair might weirdly act like a dipole, just like a hole might weirdly act like an electron?)

If we're, instead, talking about a mismatch between electrons and holes, then the resulting structure would, in fact, have charge, and thus electromagnetic attraction, and thus your meta-excitronium seems like it should be possible.

Another puzzle: Is it possible to keep multiple holes close together somehow? – Perhaps by using appropriate excitons as a glue similarly to how neutrons might work?
And if that's the case, can we get a whole set of analogous exciton-based chemistry? Even exciton-based *life forms*?

if so, that sounds like an… exciting venture for some hard science fiction novel.

Reply
Bob says:
10 December, 2017 at 1:13 pm
There's an article in October 2017 Physics Today titled The new era of polariton condensates which discusses the excitation of excitons to generate a *resonance in the polarizability of a medium* which then non-linearly amplifies photo-photon interactions producing the *thermalization* of photons leading to the *full thermal equilibration necessary for superfluidity* of a polariton BE condensate. It discusses producing an exciton with small Bohr radius for sufficient binding energy/effective mass thus generating longer exciton persistence times at room temperature.

"Electrical Engineering professors have, yes, invented lots of smoke and mirror ways of "explaining" holes in terms of classical physics, but these ways are all, really, seductive frauds."
– Paul J. Nahin in a preface to his book,**The Science of Radio**.

How are massive holes not like anti-muons?
muonium

dropleton

$10 has been donated to Wikipedia in honor of the Azimuth blog.

Reply
Phillip Somerville says:
10 December, 2017 at 3:50 pm
Puzzle 2. Koch snowflakes made of Menger sponge!

Reply
@whut says:
10 December, 2017 at 5:07 pm
Regarding the qualifier "In certain crystals", I just wanted to point out that knowledge of excitons is widespread in the semiconductor industry. Millions of research dollars have been spent over the years in characterizing high-speed semiconductor and laser materials through techniques such as photoluminescence (PL) analysis to evaluate the lifetime of excitons. I recall going to conferences years ago where every presentation had the requisite PL analysis.

Here's a review article:
Use of excitons in materials characterization of semiconductor system

So if some semiconductor researcher is reading this post, it might give them some ideas for a new research path.

Reply