

The natural and technological world around us

The what, why, and who of condensed matter physics research

Inna Vishik

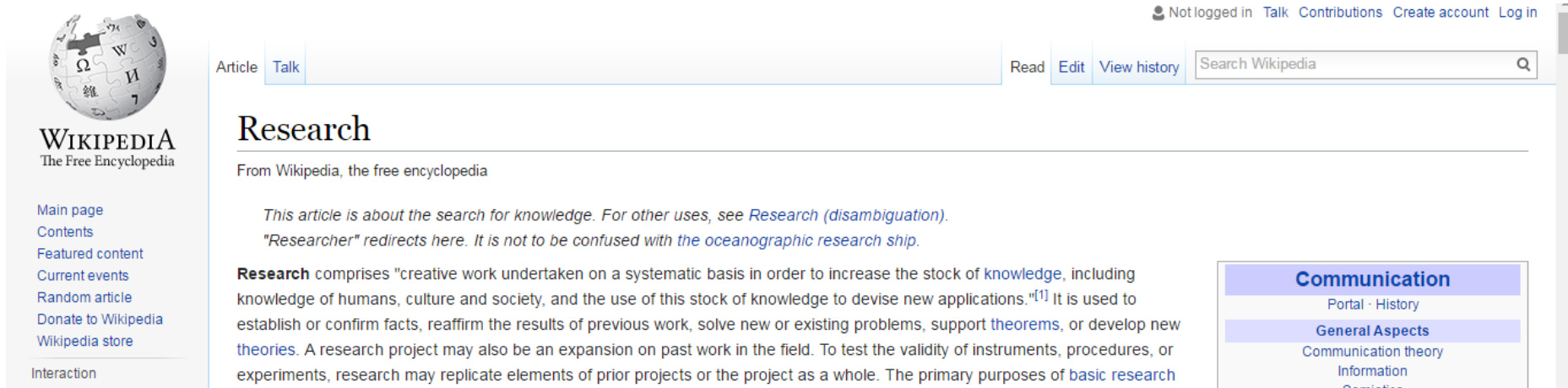
UC Davis

Jan 31, 2017

Outline

- Basic vs applied research
- Why do we do research?
- Condensed matter physics research
- My condensed matter physics research

What is research?



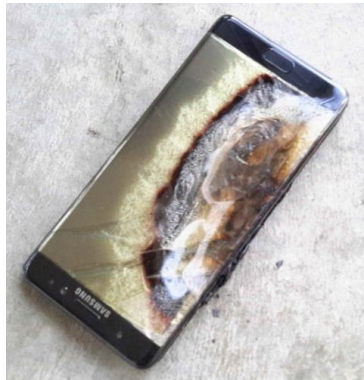
The image shows a screenshot of the Wikipedia article for "Research". At the top left is the Wikipedia logo, a globe with various symbols, and the text "WIKIPEDIA The Free Encyclopedia". Below the logo are links for "Main page", "Contents", "Featured content", "Current events", "Random article", "Donate to Wikipedia", and "Wikipedia store". At the top right, there is a user status "Not logged in" and links for "Talk", "Contributions", "Create account", and "Log in". Below this is a search bar with the text "Search Wikipedia" and a magnifying glass icon. The article title "Research" is prominently displayed, followed by the text "From Wikipedia, the free encyclopedia". Below the title is a paragraph of text: "This article is about the search for knowledge. For other uses, see *Research (disambiguation)*. *\"Researcher\"* redirects here. It is not to be confused with *the oceanographic research ship*." Below this is the main body of text: "**Research** comprises \"creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of humans, culture and society, and the use of this stock of knowledge to devise new applications.\"^[1] It is used to establish or confirm facts, reaffirm the results of previous work, solve new or existing problems, support **theorems**, or develop new **theories**. A research project may also be an expansion on past work in the field. To test the validity of instruments, procedures, or experiments, research may replicate elements of prior projects or the project as a whole. The primary purposes of **basic research**". On the right side of the article, there is a sidebar with a blue header "Communication" and sub-links "Portal · History", and another blue header "General Aspects" with sub-links "Communication theory", "Information", and "Societies".

- Creative
- Systematic
- Increasing shared knowledge

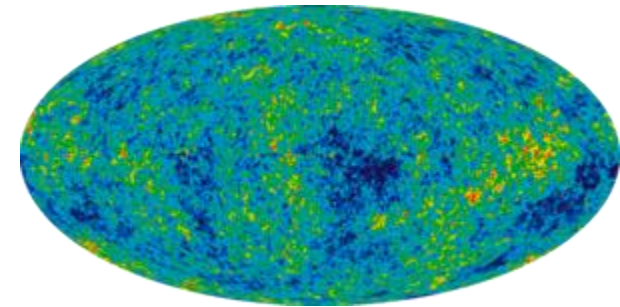
Different types of research

Applied
Research

Basic
Research



How do I make sure the
next Samsung galaxy phone
does not explode??



What happened in the first few
minutes after the Big Bang?

Why do we do *basic* research?

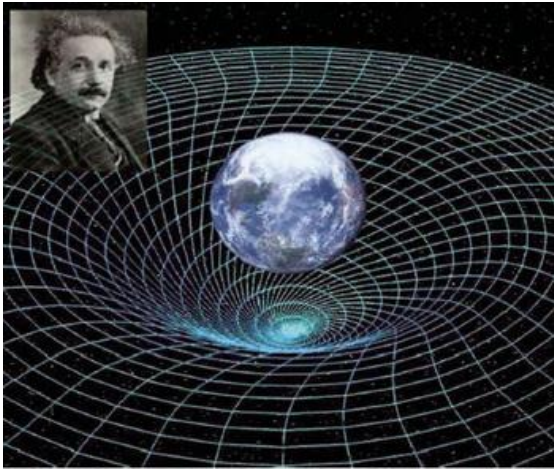
- It's interesting
- It's fulfilling
- It satisfies (part of) humans' desire to understand their world
- It's profitable (for society)



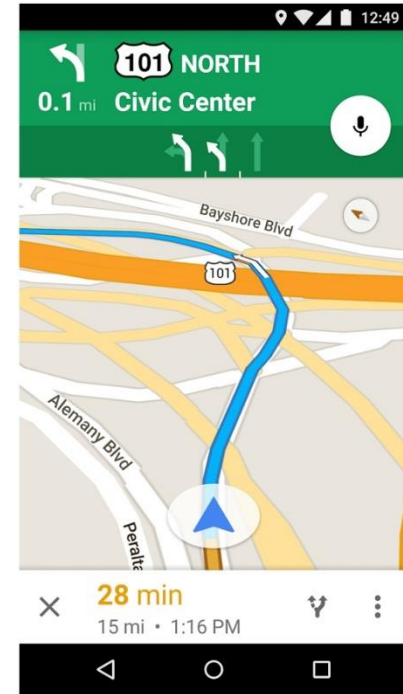
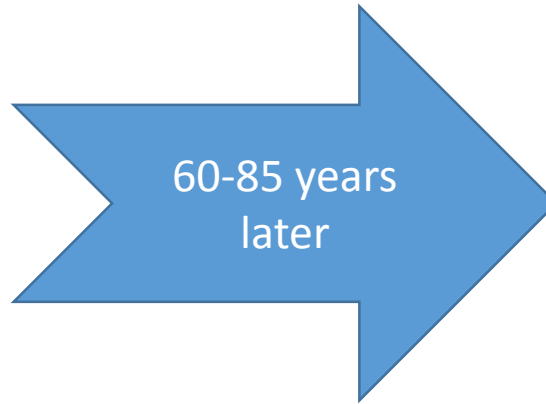
How does society benefit from basic research?

- Educated workforce who has experience solving difficult, open-ended problems
- Technology transfer
- Unexpected applications which are realized decades in the future

Examples of unexpected applications of physics research

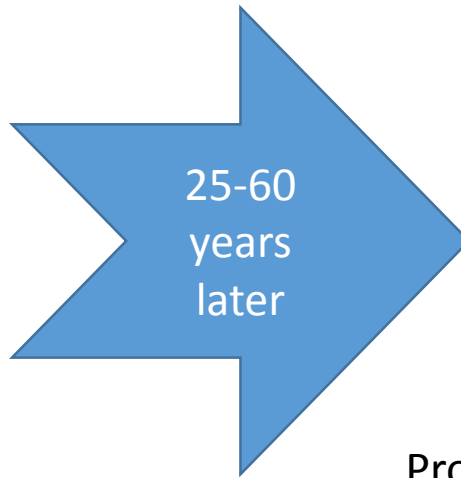
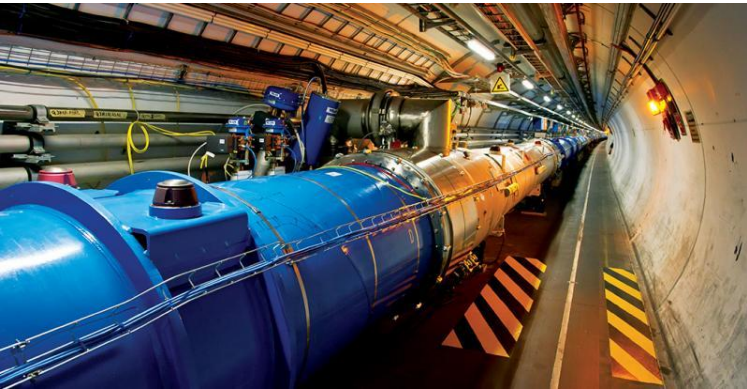


Einstein's theory of special relativity (1915) → how does spacetime curve around massive astronomical bodies?



Clocks on GPS satellites make corrections relative to observers on earth using Einstein's theories

Examples of unexpected applications of physics research



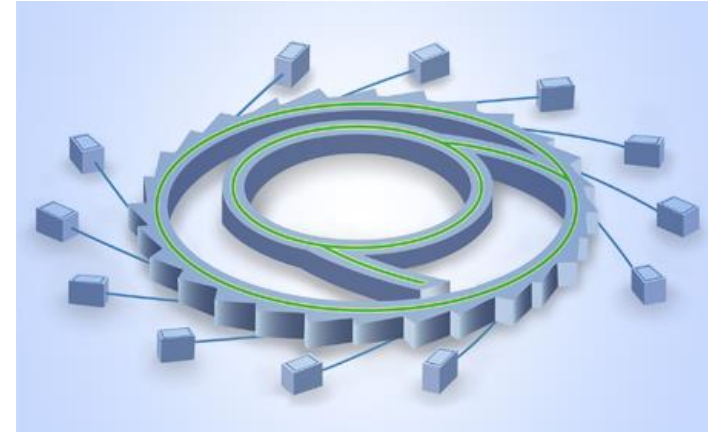
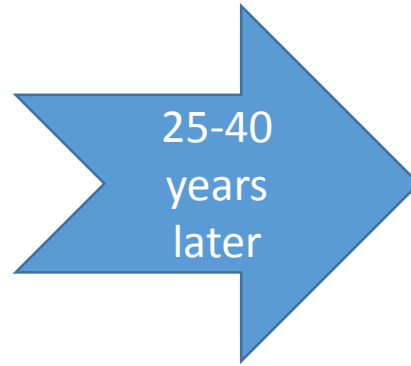
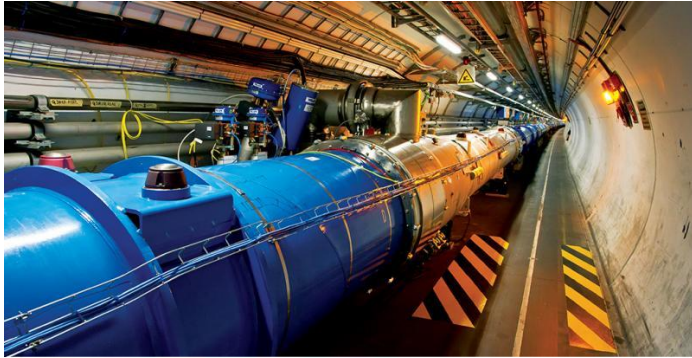
Particle accelerators: smash subatomic particles into each other in order to investigate fundamental interactions and structures

Proton therapy: use energetic beam of protons from particle accelerator to selectively target cancerous tissue

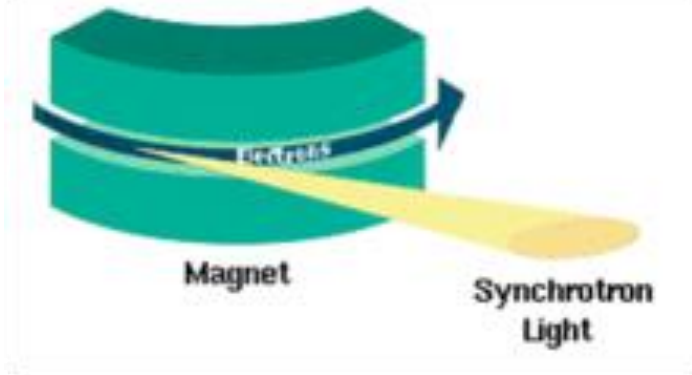
Also the WWW!



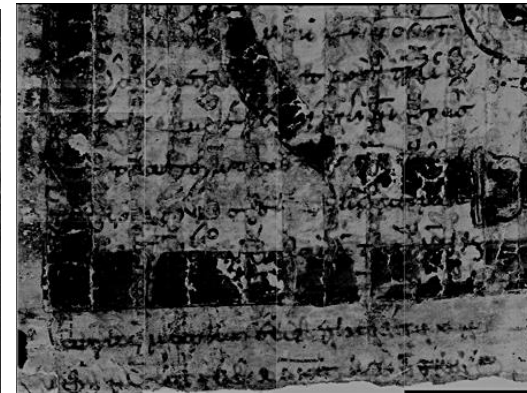
Sometimes the unexpected application of research is more research



Dedicated synchrotrons produce bright x-rays for doing experiments in physics, chemistry, biology, engineering, art....

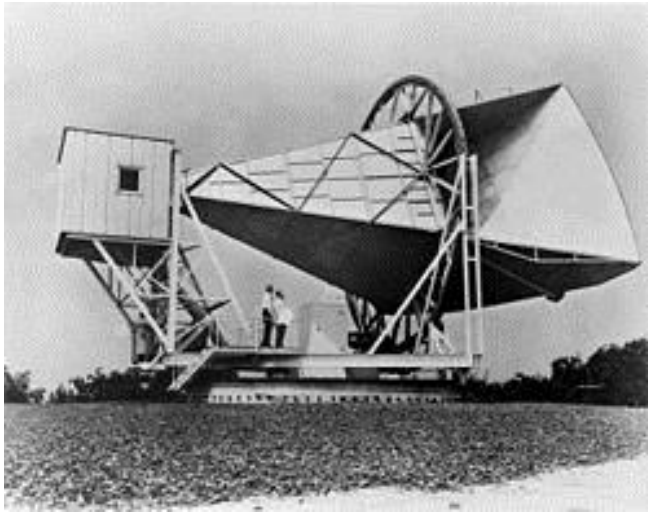


Circular particle accelerators emit x-rays—synchrotron light

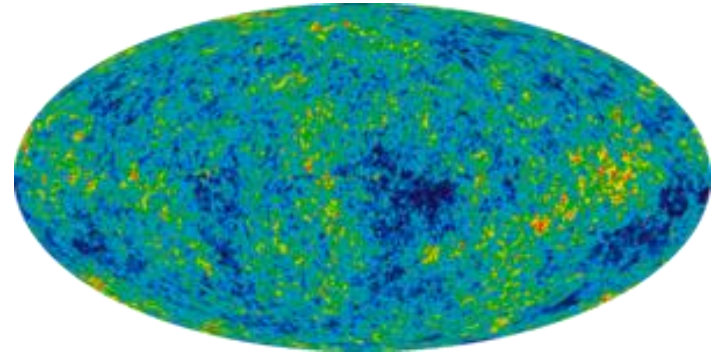
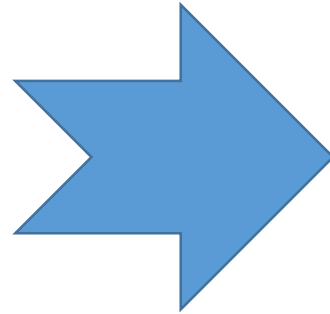


Yes, art! Archimedes palimpsest

And sometimes applied research leads to insights in basic science



Researchers at Bell Labs were using a microwave horn antenna to communicate with satellites (1960s)



They discovered a microwave background permeating outer space—an echo of the Big Bang

Summary: the what and why of research

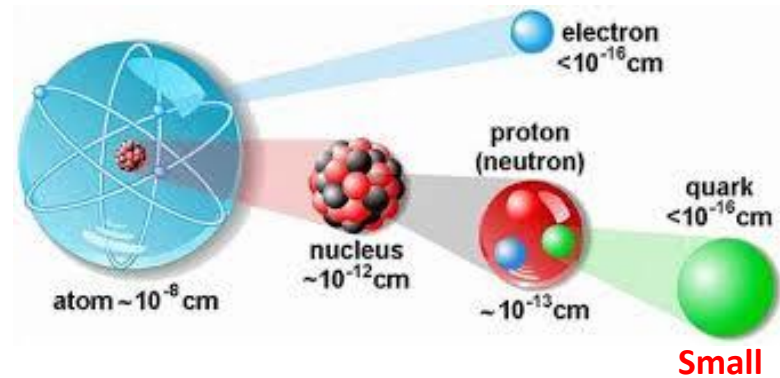
- It's profitable (estimated return on investment: 30-700%*)
- Applied research aims for short-term profitability
- Basic research aims to amass important ideas, discoveries, and invention for the next generation's economic profits
- Important feedback loop between applied and basic research

Many types of physics research

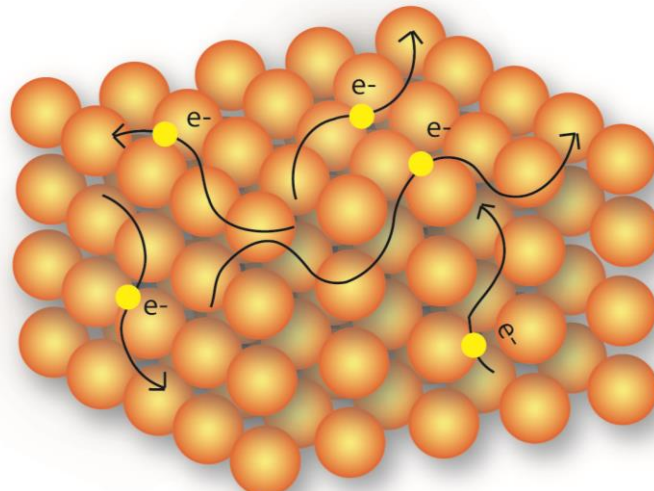
Astrophysics



Particle physics



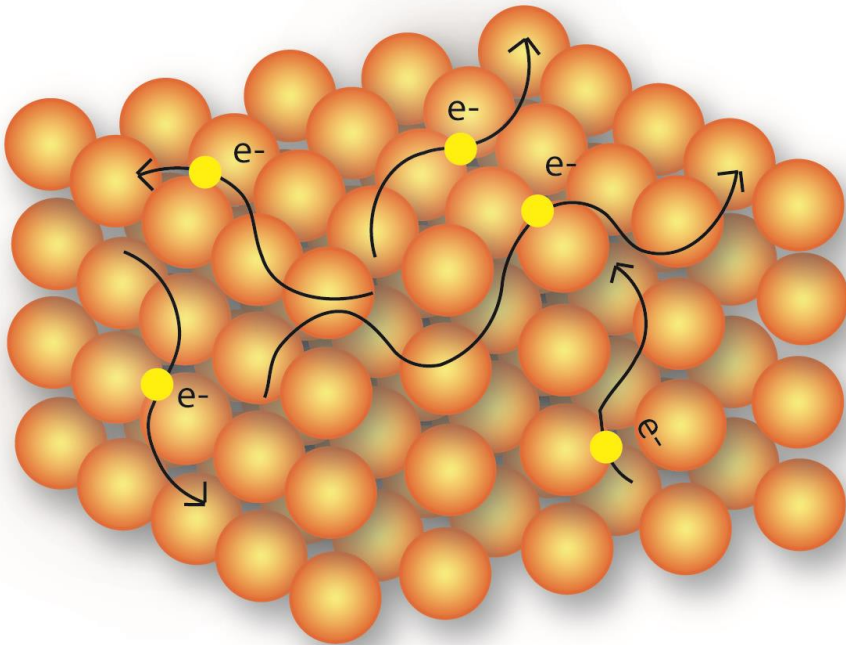
Condensed matter physics



many many many many many many many many



Condensed matter physics: the physics of many

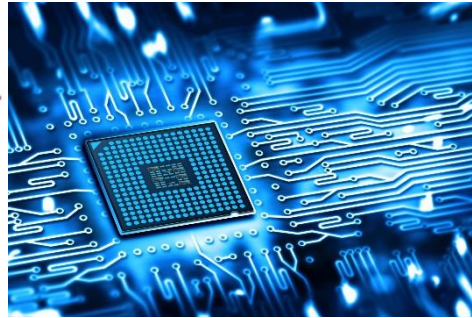


What happens when $\sim 10^{23}$ electrons interact with each other and with $\sim 10^{23}$ positively charged nuclei which are arranged in an orderly lattice

It turns out that basically an infinite number of things can happen...



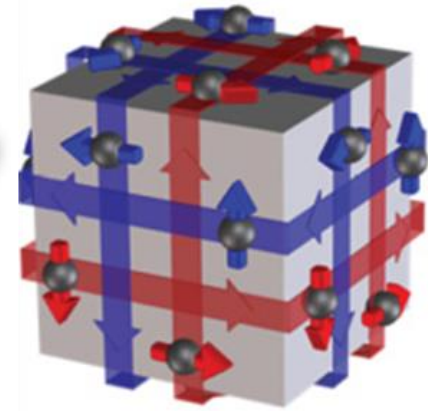
metal



Semiconductor



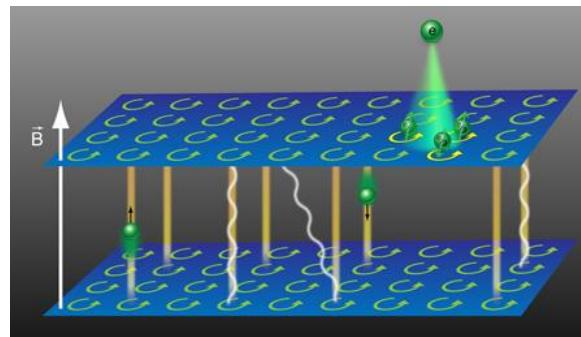
Insulator



Insulator in bulk,
metal on surface



Magnet (and materials
which respond to magnet)



Materials which behave as if
electrons inside have *fractional*
charge (fractional quantum hall
effect)



Magnetic monopoles are elusive particles
that have never been observed

Materials which behave as if
they contain magnetic north
poles without corresponding
south poles

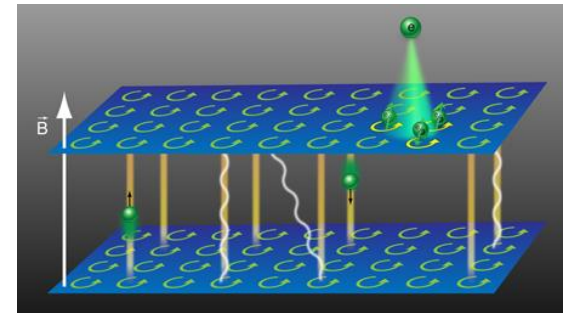
Is condensed matter physics basic or applied research?

Applied
Research

Basic
Research



Understanding how impurities in silicon and other semiconductors could be manipulated to make transistors is crucial to all modern electronic devices



These same semiconductors, when prepared in a special way and cooled down to almost absolute zero can host 'fractionally charged electrons'

Condensed matter physics is both **useful** and **fundamental**

Condensed matter physics is both mundane and fantastical

Mundane

Holy
guacamole

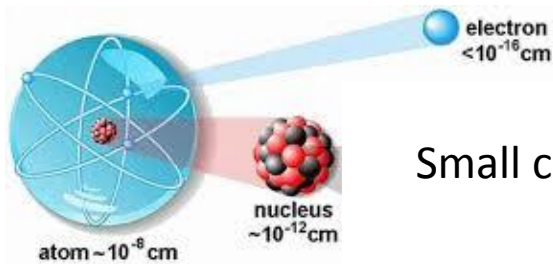


Why is window glass transparent?



Materials that expel their magnetic field when they are cooled (superconductors), and levitate above magnets (Video source: goo.gl/H6kXSW)

Condensed matter physics is simultaneously **small** and **large**



Small constituents

Large magnets

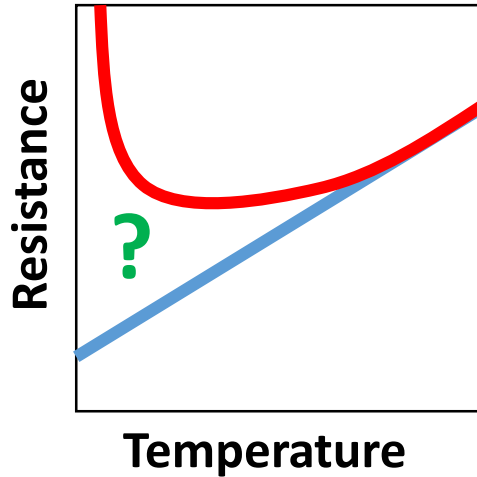


Tabletop experiments

Large facility experiments (e.g. synchrotron)



Condensed matter physics is a science which relies on serendipity

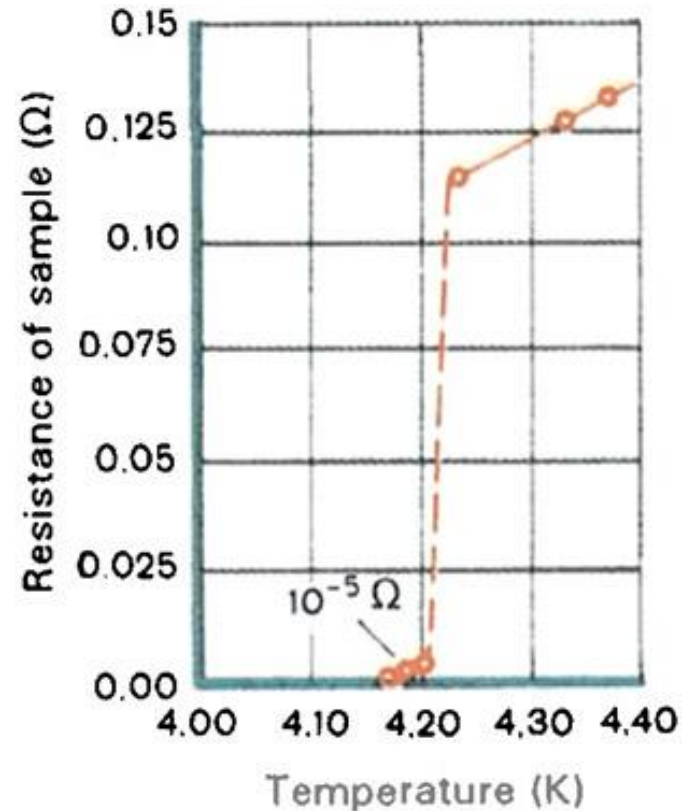


H. Kamerlingh Onnes

Mercury



Liquid helium



Surprise discovery: resistance to flow of electricity suddenly goes to zero (a superconductor)

Physicists want to **explain** surprising phenomena



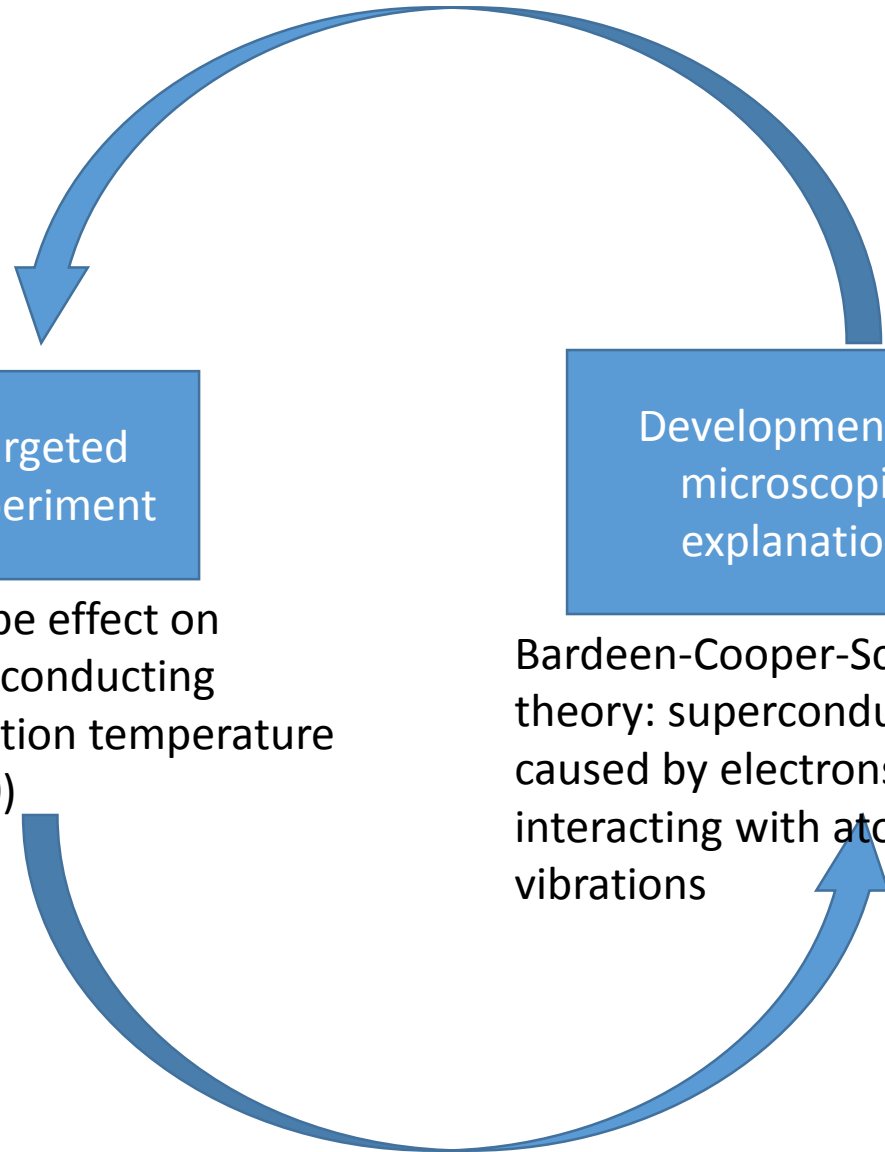
Superconductivity is useful (e.g. MRI machines), but how does it work?

Targeted experiment

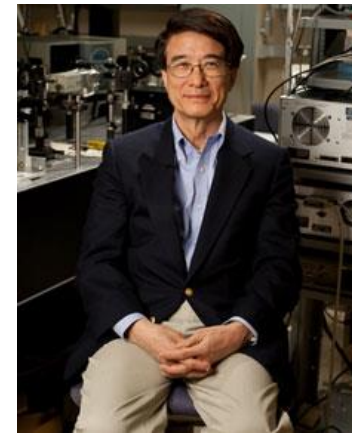
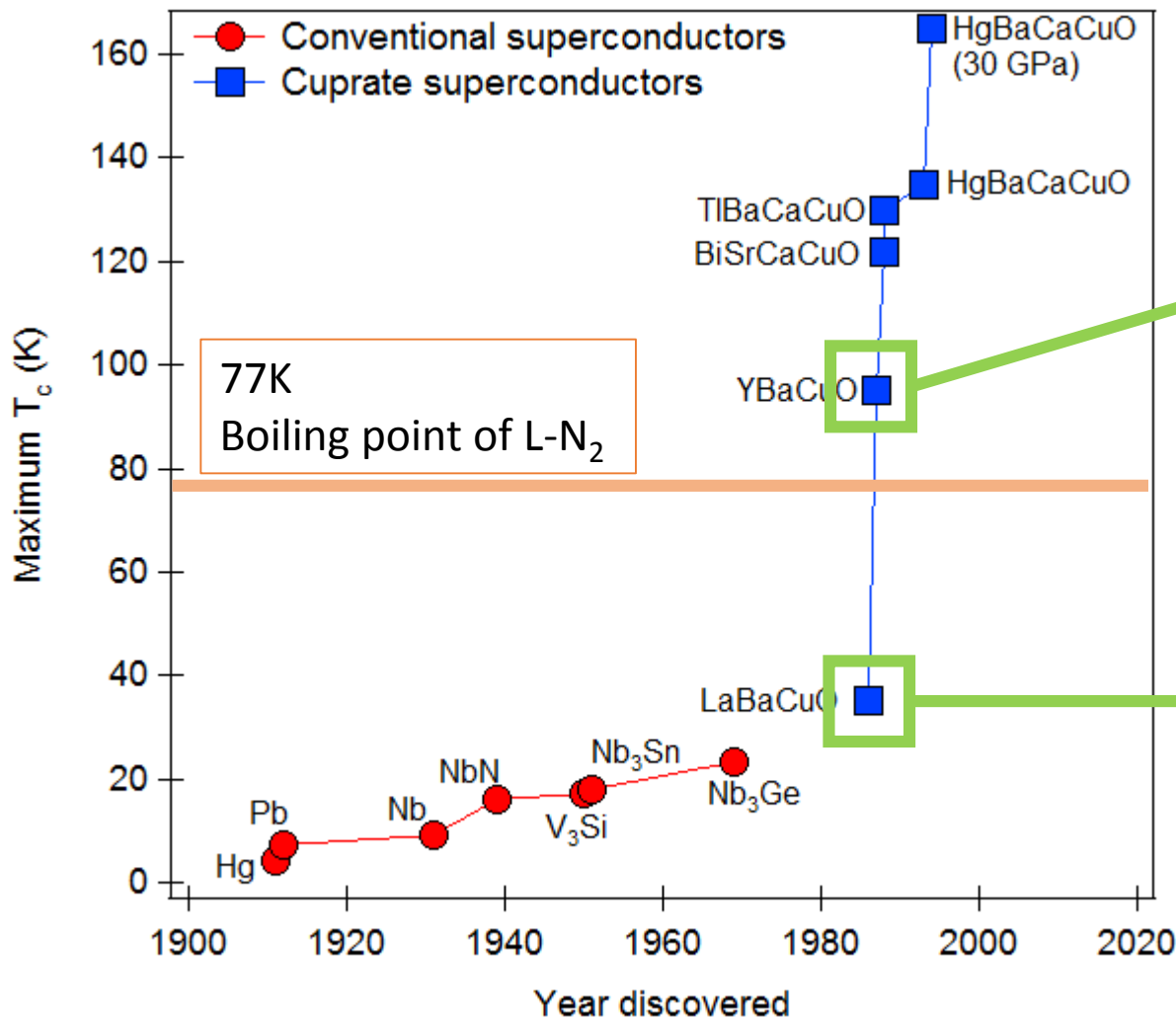
Isotope effect on superconducting transition temperature (1950)

Development of microscopic explanation

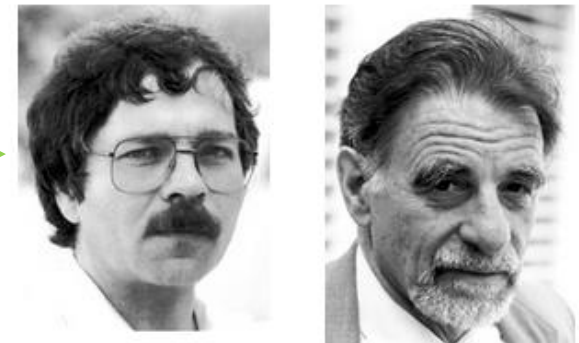
Bardeen-Cooper-Schrieffer theory: superconductivity caused by electrons interacting with atomic vibrations



When a problem is 'completely solved', sometimes we can still get a surprise



Paul Chu



Bednorz and Muller
Nobel prize 1987

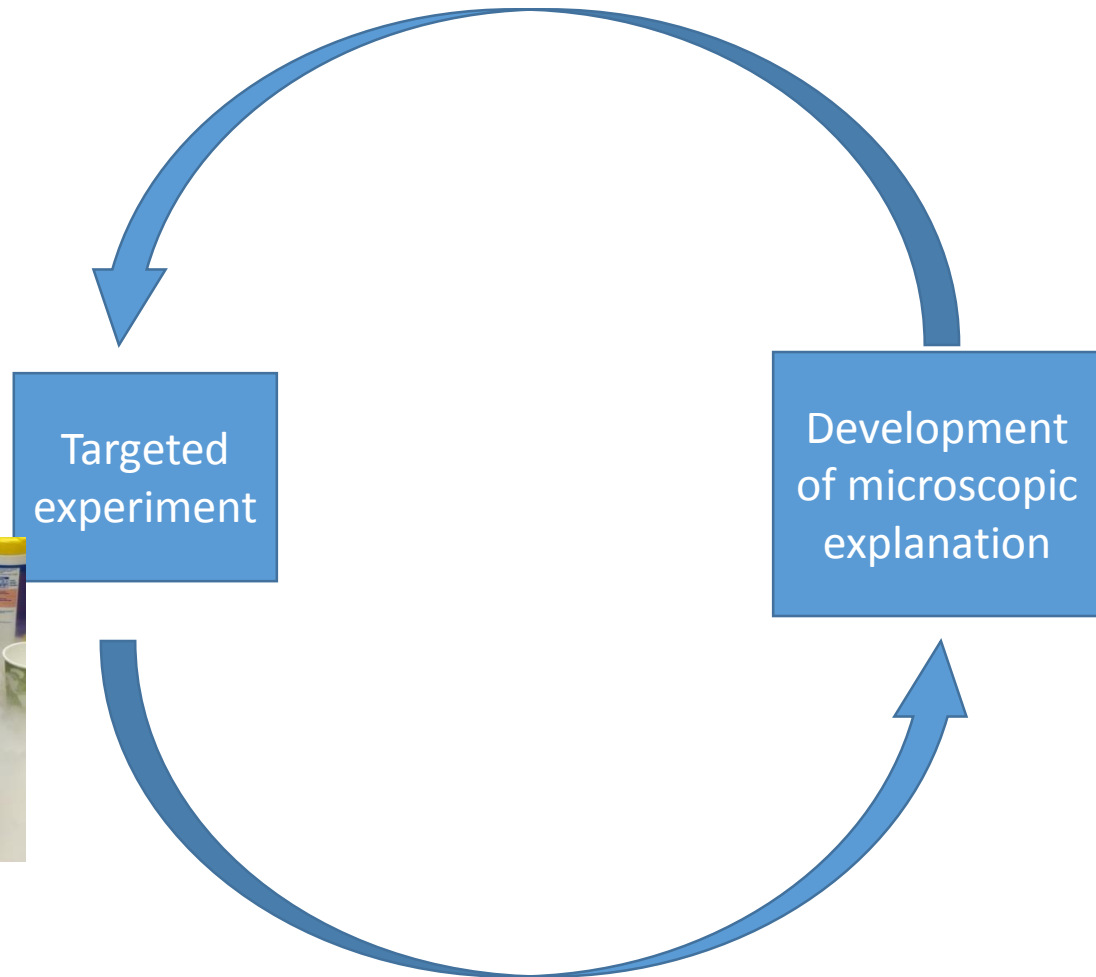
Mechanism of 'high-temperature' superconductivity in copper-oxides still not explained



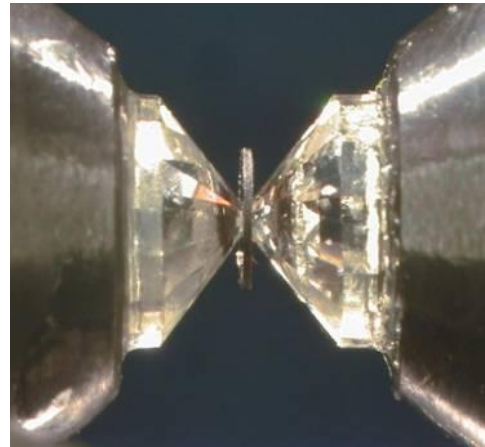
Liquid helium
~\$15/Liter



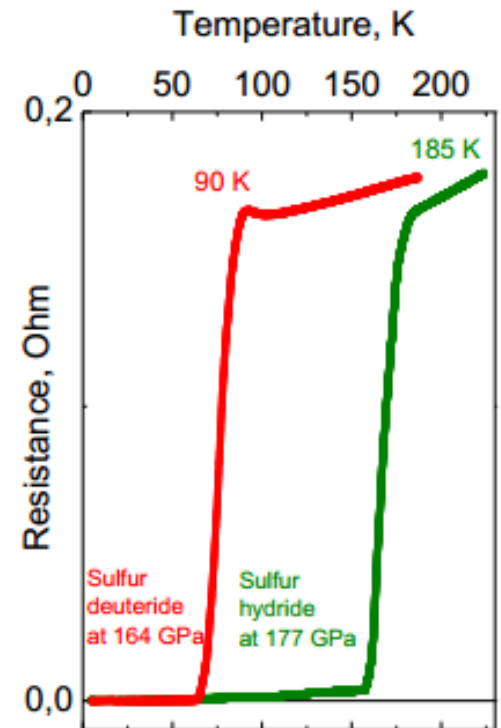
Liquid nitrogen
~\$0.30/Liter



Past ~3 years: make 'high-temperature' superconductors by mashing hydrides between diamonds



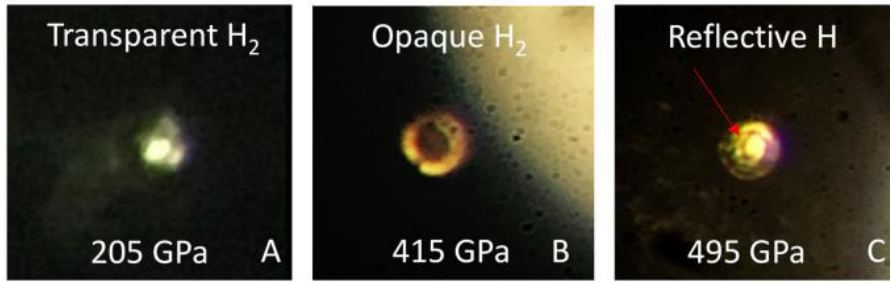
Drozdov *et al.*
ArXiv: 1412.0460



Highest superconducting T_c :
onset > 190 K!

Metallic hydrogen is **predicted** to be a **room temperature** superconductor and it was (allegedly) created for the first time last week

Larger than pressure
in center of earth!!

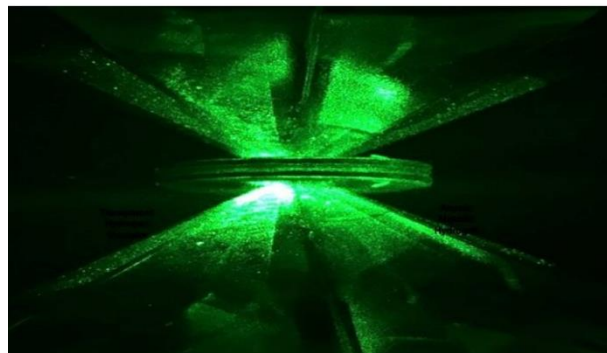


R. P. Dias et al., Science
10.1126/science.aal1579
(2017)



SCIENCE

Hydrogen Squeezed Into a Metal, Possibly Solid, Harvard Physicists Say



If some theoretical predictions turn out to be true, the new state of hydrogen could even be a solid metal that is metastable — remaining solid even after the crushing pressure is removed — and a superconductor, able to conduct electricity without resistance, Dr. Silvera said.

Dr. Silvera and Ranga P. Dias, a postdoctoral researcher, [published the findings on Thursday](#) in the journal Science.

But in the small but contentious field of high-pressure physics, some scientists who perform similar experiments were harshly skeptical and wondered how the research passed peer review at a top journal like Science.

“It’s — how should I put it? — the product of Ike’s imagination from the title to the end,” said Eugene Gregoryanz, a physicist at the University of Edinburgh in Scotland.

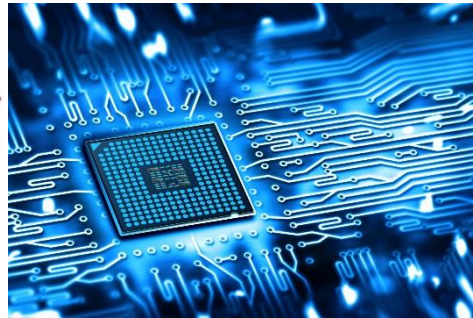
Paul Loubeyre, a physicist at France’s Atomic Energy Commission, wrote in an email, “The fact that the paper went through illustrates the fact that the reviewing process has some flaws.”

Stay
tuned!

Reminder: superconductivity is not the only fun/useful thing that happens in materials



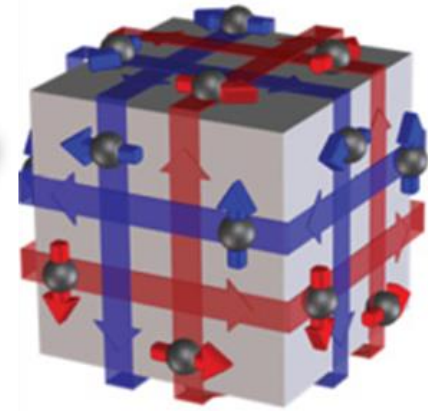
metal



Semiconductor



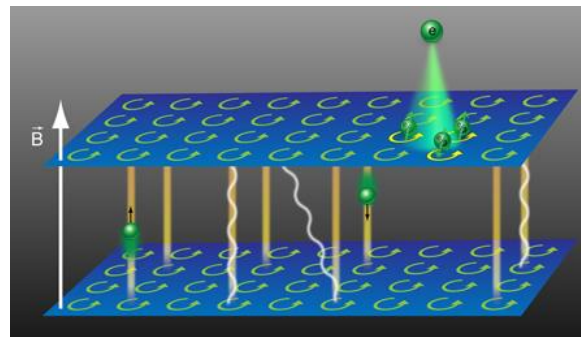
Insulator



Insulator in bulk,
metal on surface



Magnet (and materials
which respond to magnet)

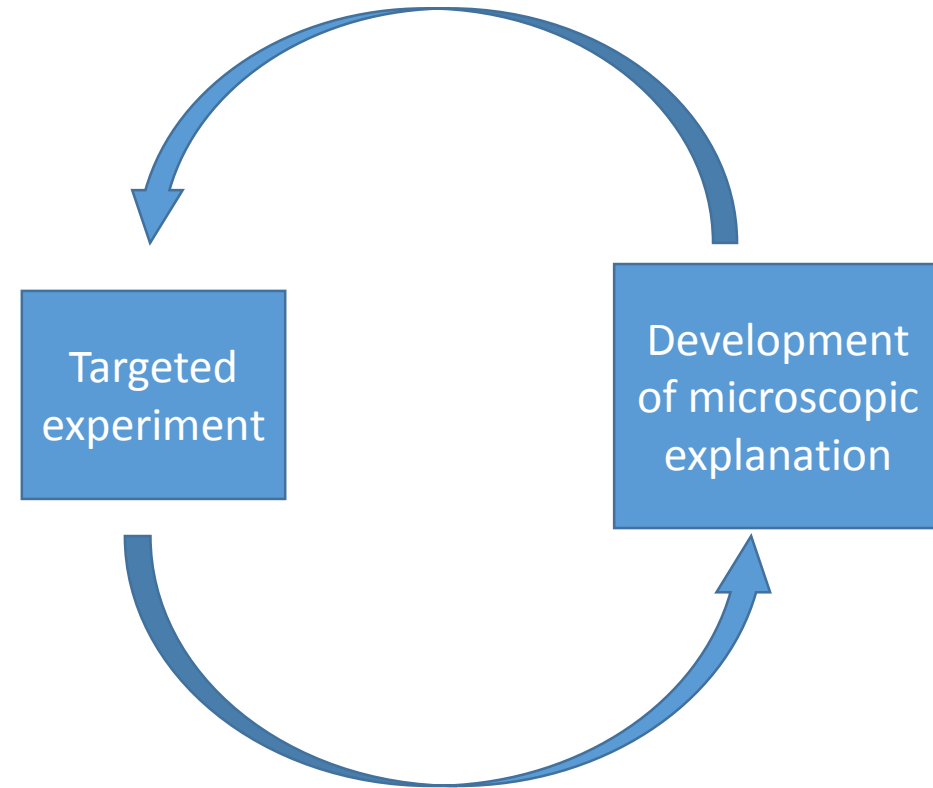
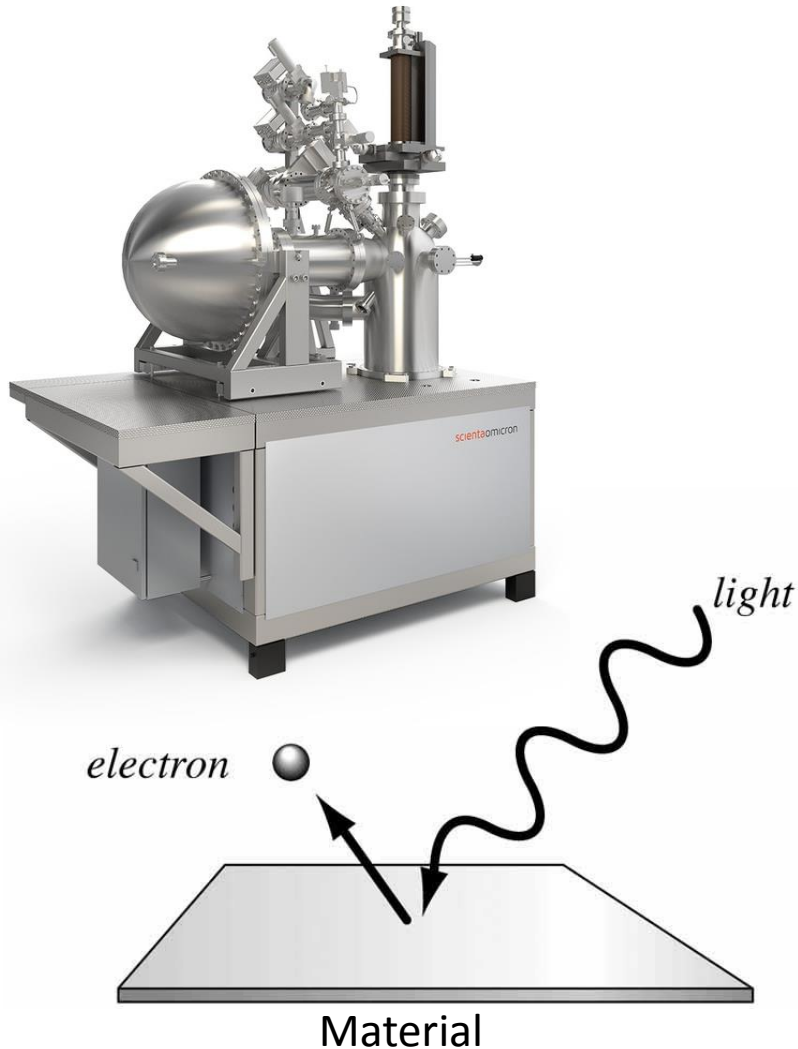


Materials which behave as if
electrons inside have *fractional*
charge (fractional quantum hall
effect)

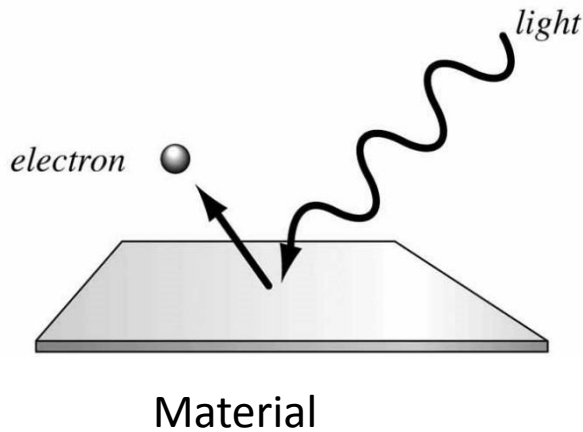


Materials which behave as if
they contain magnetic north
poles without corresponding
south poles

The diversity of materials' properties largely originates from electrons



Why study electrons in this way?



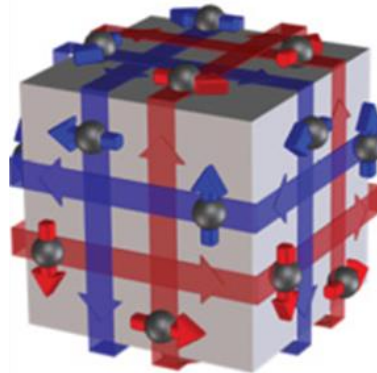
Electrons ejected (photoemitted) by light still carry information about how they were moving in the material

Superconducting materials:



→ measure energy to de-pair superconducting electrons

Topological insulators (insulator in bulk, indestructible metal on surface)

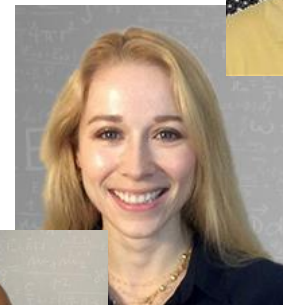


→ Distinguish between surface and bulk electrons and see how they interact

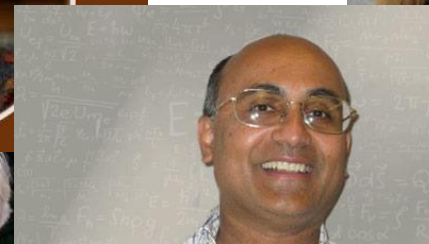
Condensed matter physics is a team effort



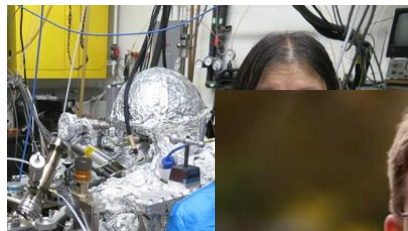
Zieve,
uniaxial
pressure



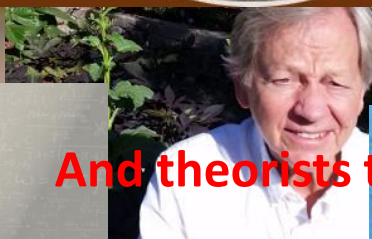
photoemission



question: What happens
trons interact
nd with
charged



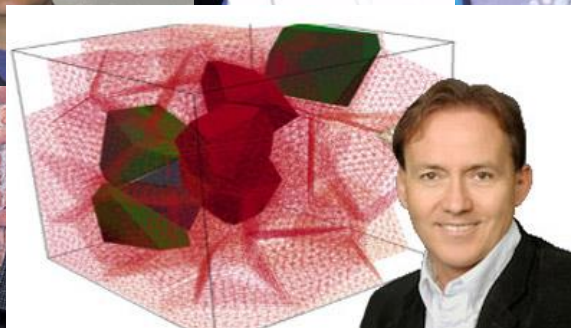
Chiang, surface



And theorists too!



Curro, NMR



M. Hamidian, STM



Fadly, xray photoemission



Taufour, xtal growth



Yu, nanocrystals



Zhu, surface
science

Conclusions

- Research is useful and profitable, often in ways that are unpredictable at the time the research is done
- Condensed matter physics studies many-particle systems in which a multitude of emergence phenomena appear
- Amazing achievements and discoveries are made daily in condensed matter physics
- Condensed matter physics is a team enterprise, in which different research groups have autonomy over a small subset of the big problems we work on

Thank you for listening!