

Welcome to Where the Arts meet Physics



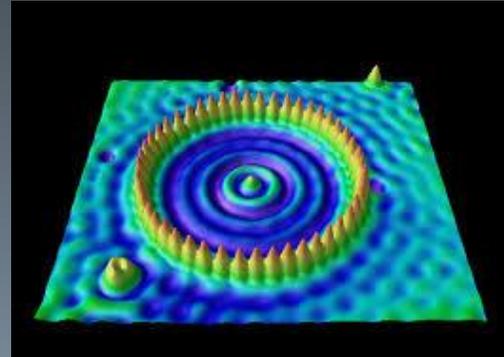
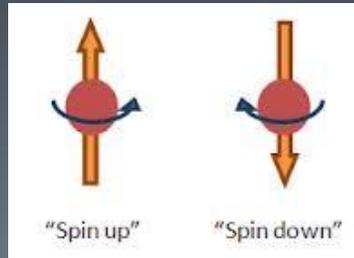
Today

- Universe Wrap-up
- Quantum World
- Quantum Voyage Audition – tmrw
- Assignment details
- Project and presentation time
- Brain-storming

[Course Website – \(Under Construction\)](#)

The Quantum World

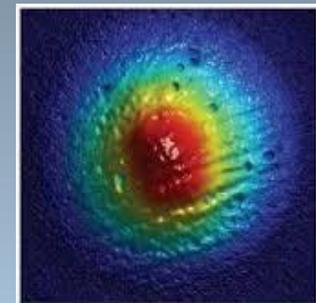
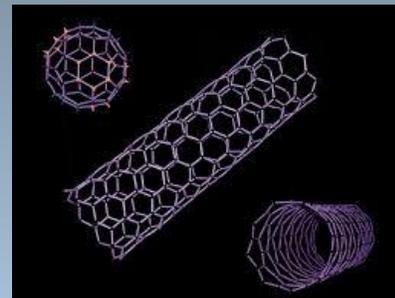
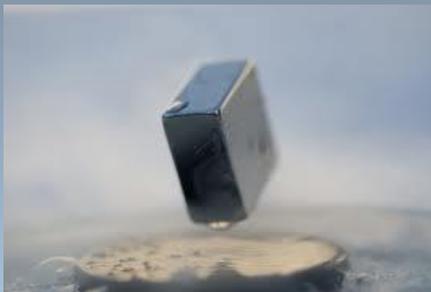
Condensed Matter, Ultra-Cold Atoms



Matter Waves

Quantum superposition
Does God play Dice?

Bizarre States
of Matter



The Story of the Quantum

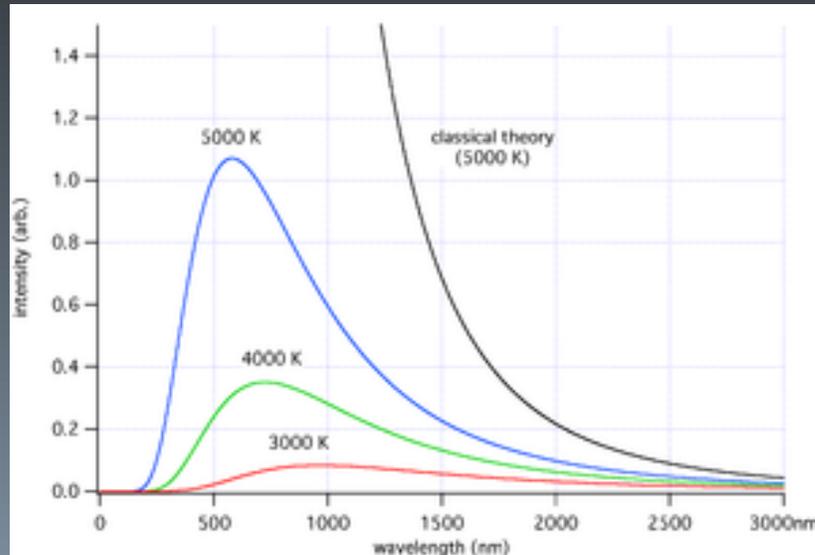
Exercise: Finding a good story

Inspiring representations (visuals, movement, etc)

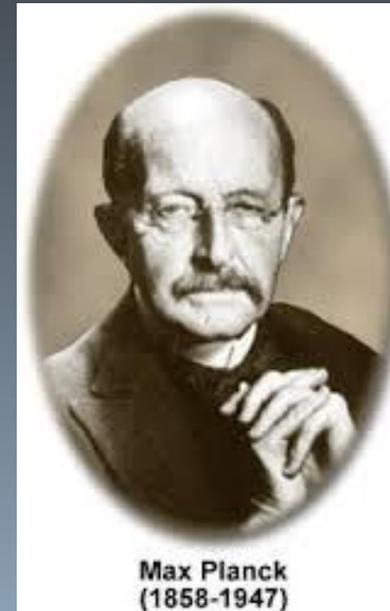
Bringing alive the quantum world

Understanding quantum paradoxes and philosophy

Birth of Quantum Physics (Early 1900's)



Blackbody radiation
Pure Electromagnetic theory
suffered 'Ultraviolet catastrophe'



**Radiated light can only have
discrete amounts of energy
that depend on frequency**

Planck relation

$$E = h \times f$$

Energy of a photon

f – frequency (Hz; per sec)

h – Planck's constant

6.6×10^{-34} Joules-sec

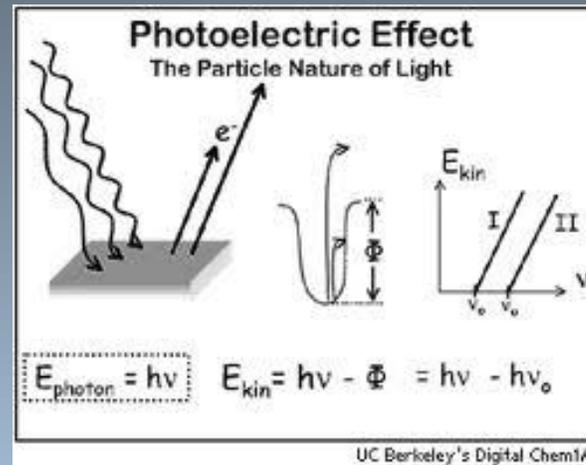
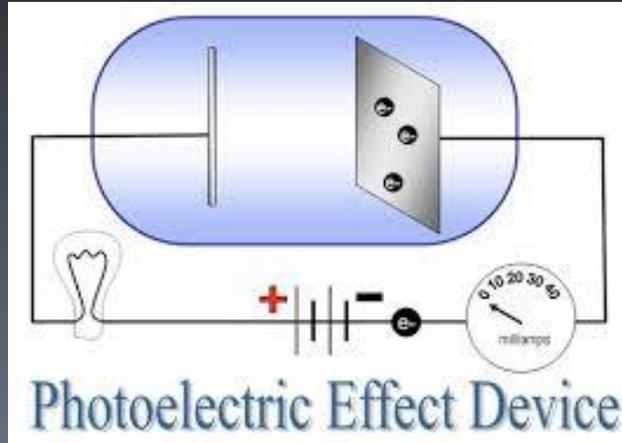
4.1×10^{-15} eV-sec



Recall: $c = L \times f$

Speed of light - c: 3×10^8 meters/sec

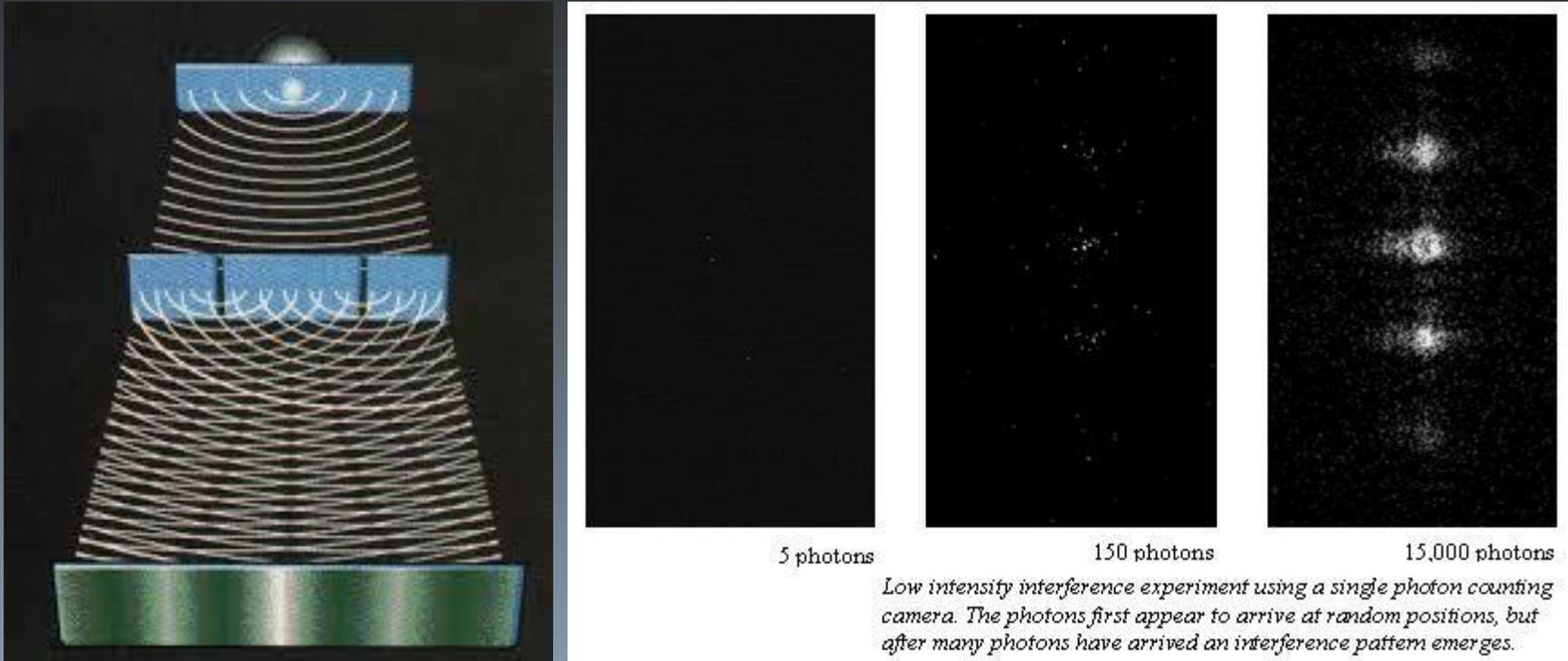
Photoelectric effect



Einstein, Nobel Prize, 1921

Photoelectric effect

Particle or wave?



E.g. Wave interference and Photon imaging

It depends!
(always one or another)

Two-slit interference

If light can behave as a particle....



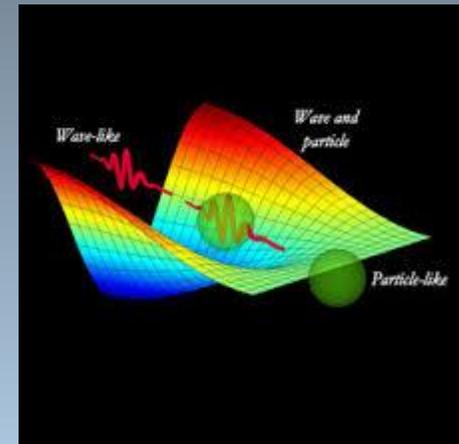
1924, PhD thesis

If light can behave as a particle.... maybe particles can behave as waves!!



1924, PhD thesis

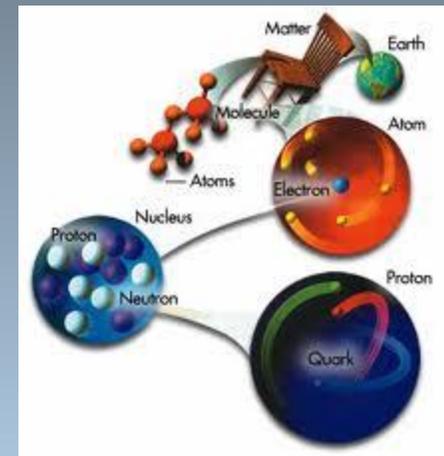
Wave-particle duality



Wave description of matter



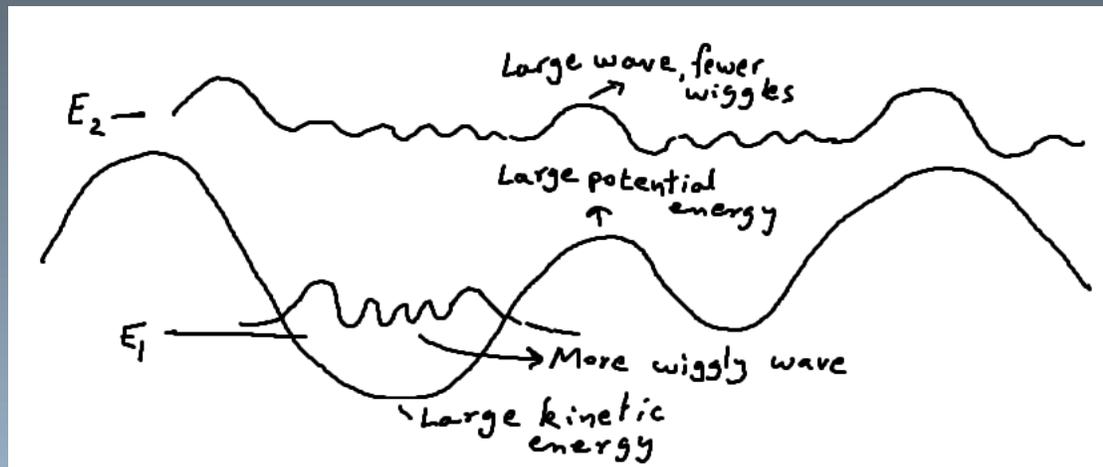
**Erwin Schrodinger
1926 – makes waves!**



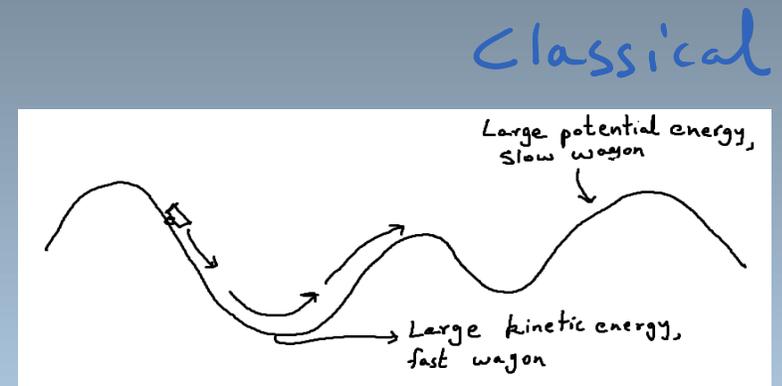
Schrödinger's Equation

$$i\hbar \frac{\partial}{\partial t} \psi = -\frac{\hbar^2}{2m} \nabla^2 \psi + V\psi$$

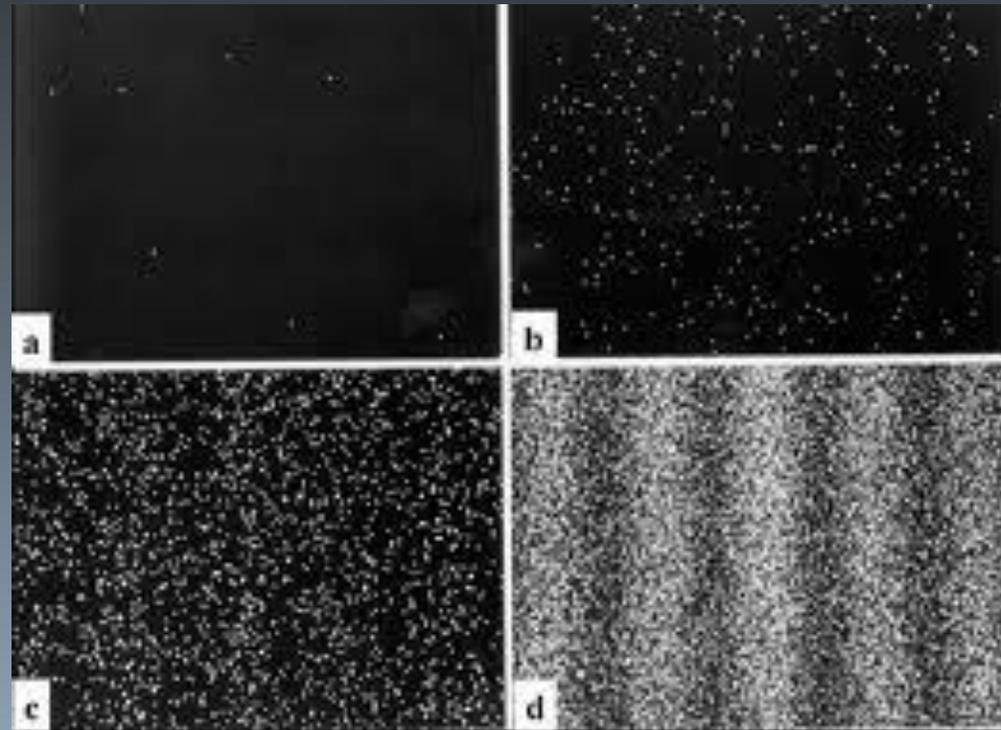
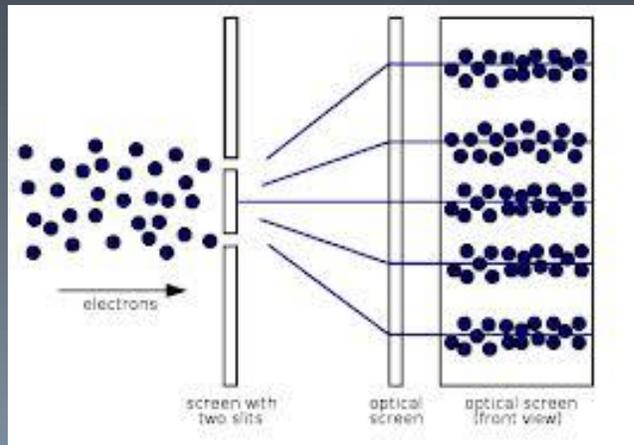
Total Energy = Kinetic + Potential



Quantum



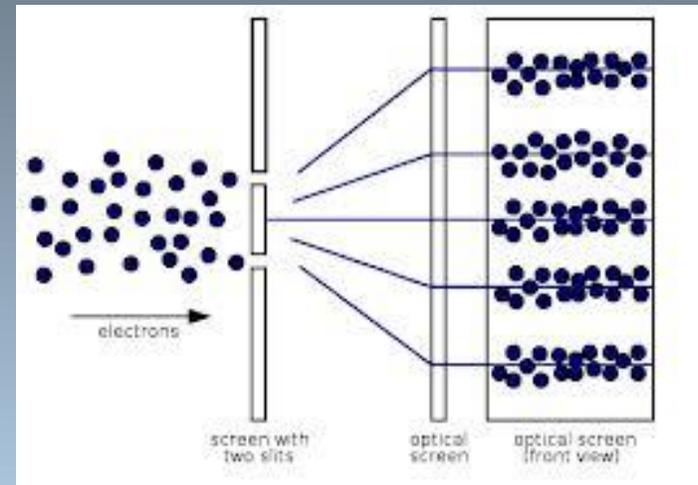
Two-slit Interference



Behavior similar to light waves!

For the two-slit interference experiment to work, a single electron must

- A. randomly go through one slit or another.
- B. go through one slit or another in synch with other electrons.
- C. go through both slits at once.
- D. None of the above

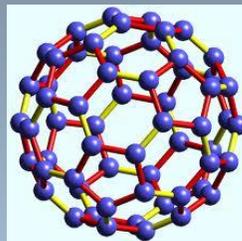


For the two-slit interference experiment to work, a single electron must

- A. randomly go through one slit or another.
- B. go through one slit or another in synch with other electrons.
- C. go through both slits at once. – Bizarre consequence of quantum physics!!!!
- D. None of the above

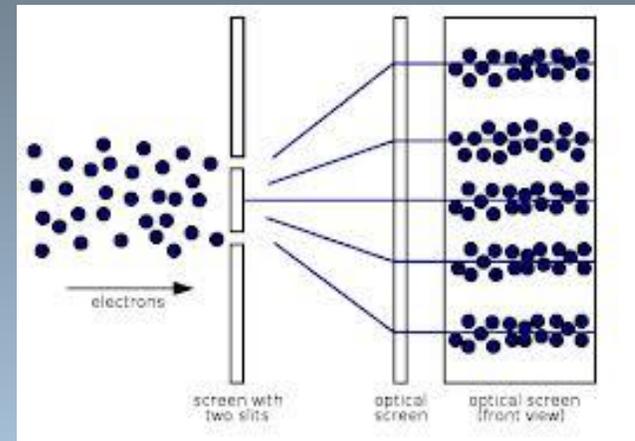
Wave-particle duality of C_{60} molecules

Markus Arndt, Olaf Nairz, Julian Voss-Andreae, Claudia Keller,
Gerbrand van der Zouw & Anton Zeilinger



“Buckyball”

Buckyball



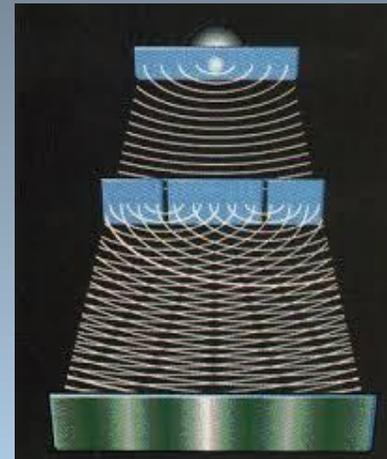
Electron diffraction

What kind of wave?

Wave of probability!!

Particle is in a 'superposition' of many places at once.....

Copenhagen Interpretation

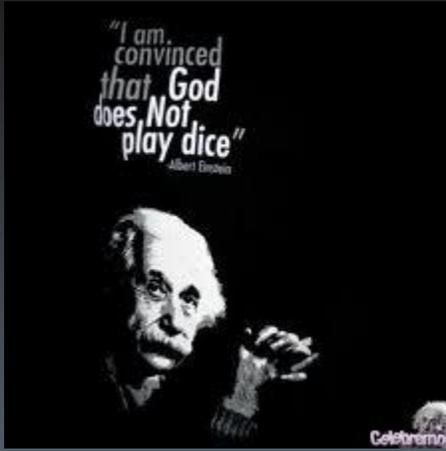


Which 'probabilistic' scenario is a direct consequence of quantum physics?

- A. The outcome of rolling a dice in Las Vegas
- B. An object exists in many places at once with some probability
- C. Predicted chance of rainfall today
- D. All of the above

Which 'probabilistic' scenario is a direct consequence of quantum physics?

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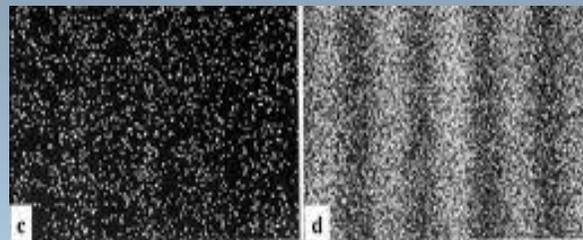


Probability and chance in the deepest sense



Wave of probability!!

Particle is in a 'superposition' of many places at once....until....it is observed!

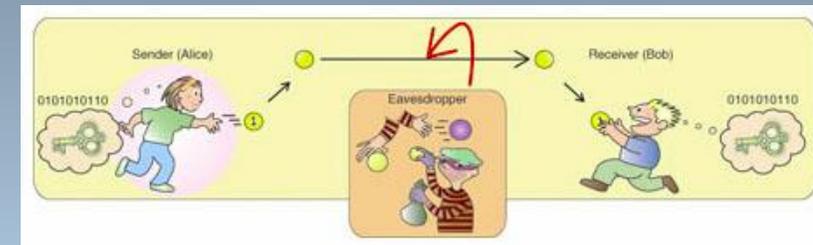
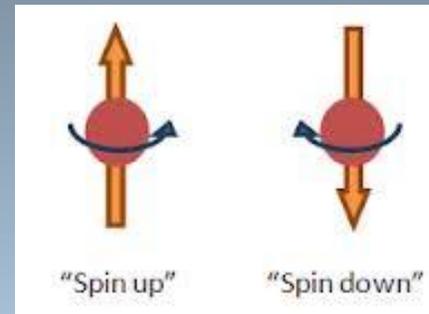
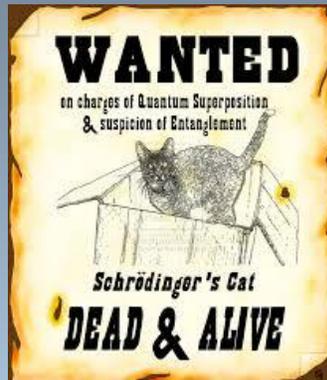


Applications of quantum superposition include

- A. Schrodinger's cat
- B. Magnetic resonance imaging
- C. Cryptography and Computation
- D. All of the above

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THE PRESENT SITUATION IN QUANTUM MECHANICS: A TRANSLATION OF SCHRÖDINGER'S "CAT PARADOX" PAPER

JOHN D. TRIMMER*

INTRODUCTION

This is a translation of Schrödinger's three-part 1935 paper¹ in *Die Naturwissenschaften*. Earlier that same year there had appeared the Einstein, Podolsky, Rosen paper² (also famous in "paradoxology") which, Schrödinger says, in a footnote, motivated his offering. Along with this article in German, Schrödinger had two closely related English-language publications.³ But the German, aside from its one-paragraph presentation of the famous cat, covers additional territory and gives many fascinating insights into Schrödinger's thought. The translator's goal has been to adhere to the logical and physical content of the original, while at the same time trying to convey something of its semi-conversational, at times slightly sardonic flavor.

7. The ψ -function as Expectation-catalog

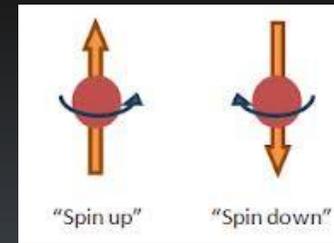
Continuing to expound the official teaching, let us turn to the already (Sect. 5) mentioned ψ -function. It is now the means for predicting probability of measurement results. In it is embodied the momentarily-attained sum of theoretically based future expectation, somewhat as laid down in a *catalog*. It is the relation- and-determinacy-bridge between measurements and measurements, as in the classical theory the model and its state were. With this latter

One can even set up quite ridiculous cases. A cat is penned up in a steel chamber, along with the following diabolical device (which must be secured against direct interference by the cat): in a Geiger counter there is a tiny bit of radioactive substance, so small, that *perhaps* in the course of one hour one of the atoms decays, but also, with equal probability, perhaps none; if it happens, the counter tube discharges and through a relay releases a hammer which shatters a small flask of hydrocyanic acid. If one has left this entire system to itself for an hour, one would say that the cat still lives *if* meanwhile no atom has decayed. The first atomic decay would have poisoned it. The ψ -function of the entire system would express this by having in it the living and the dead cat (pardon the expression) mixed or smeared out in equal parts.

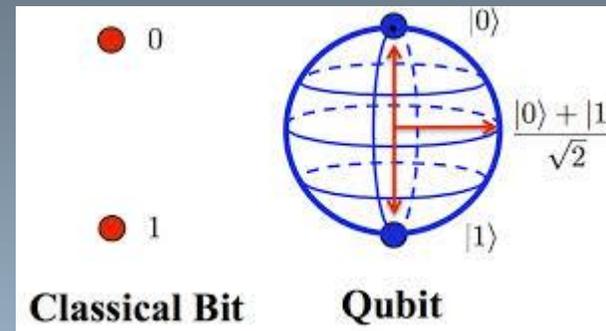
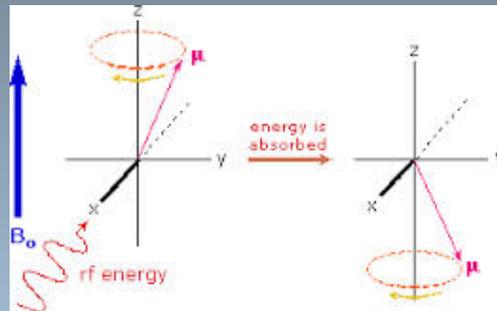
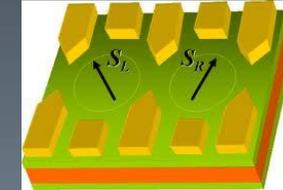
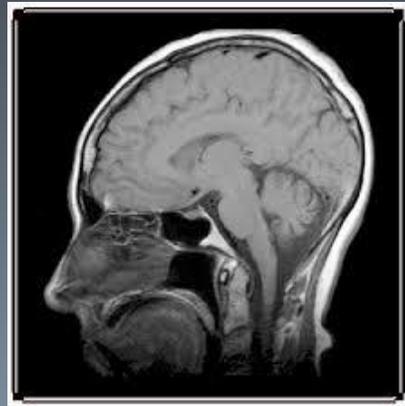


Superposition of spins

Simultaneously point up and down

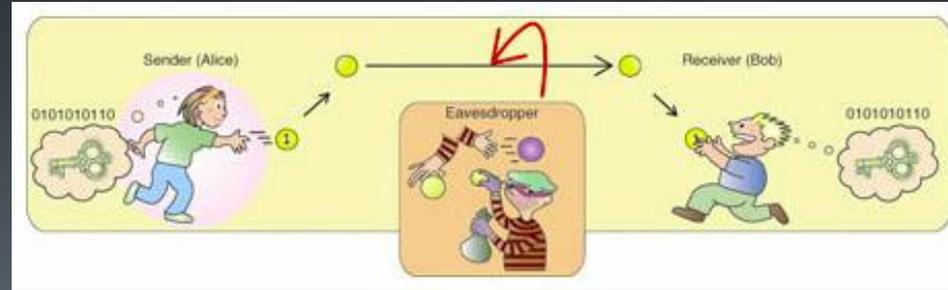
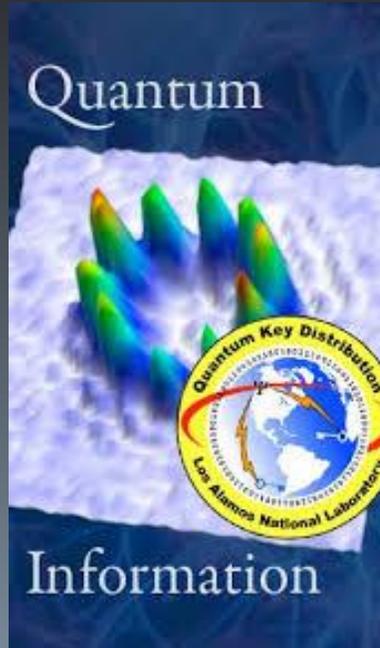


Magnetic Resonance Imaging



Quantum Computation

Quantum Information and Cryptography



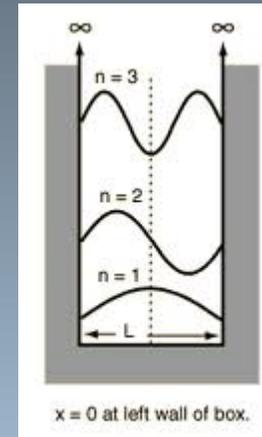
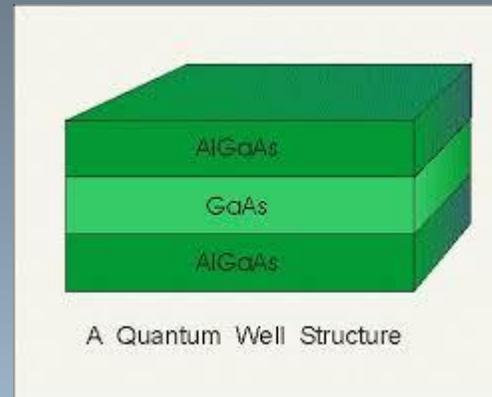
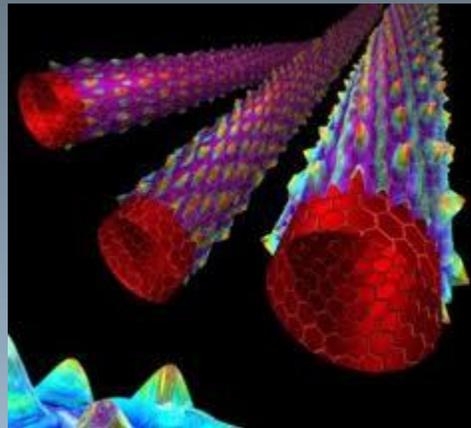
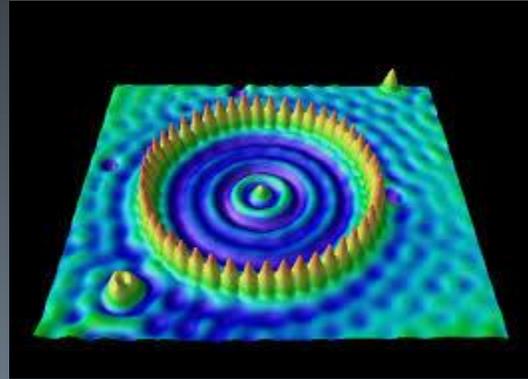
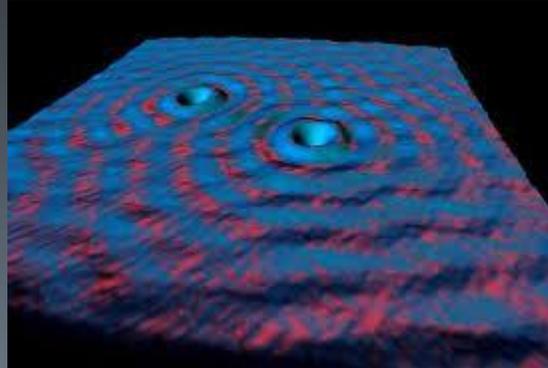
Quantum Entanglement (Spooky actions at a distance...); EPR paper

Philosophical; Applied

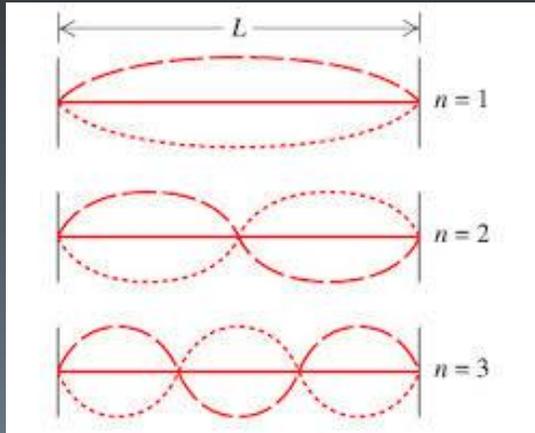


Govt and quantum encryption

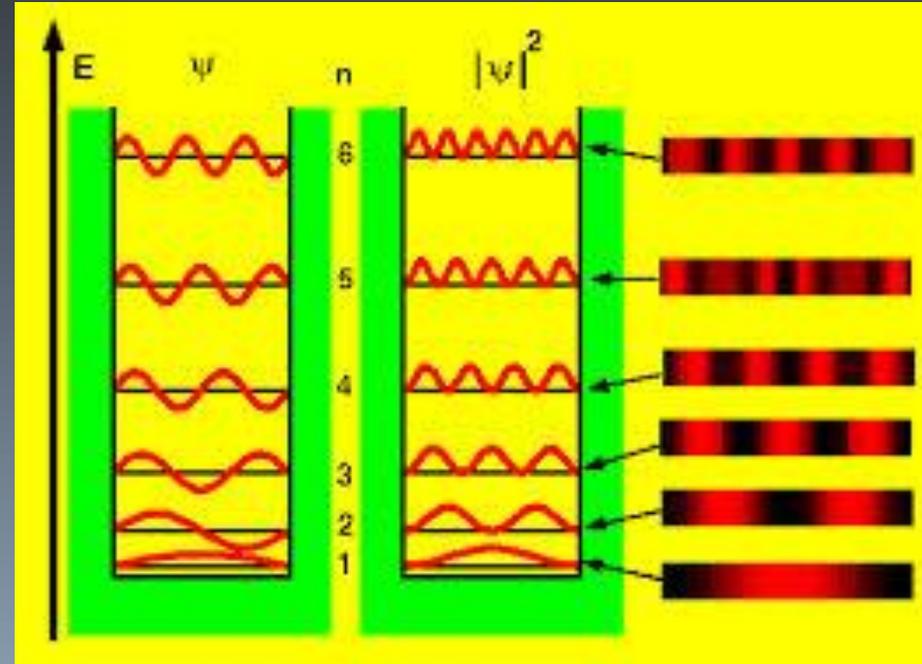
Electron Quantum Waves



Quantum particle in a box



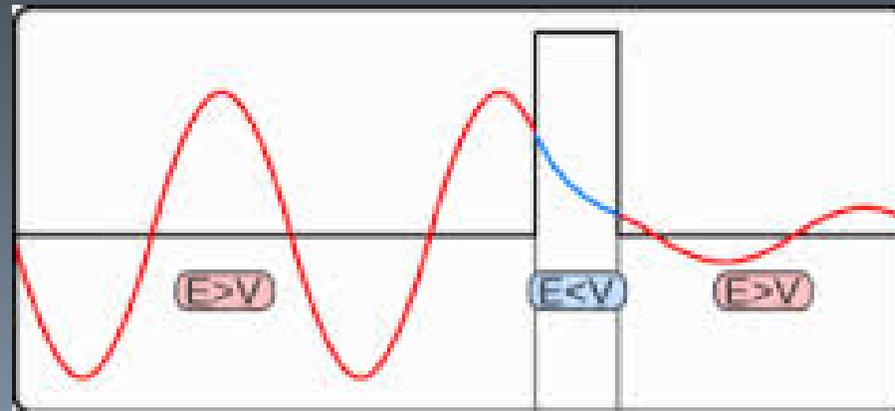
Picture:
waves and strings



Only some wavelengths
Energy 'quantized'; $E = hf$

Quantum Tunneling

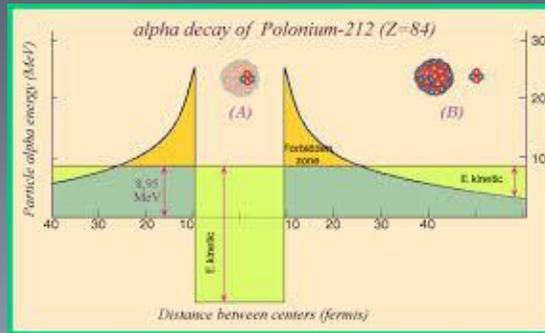
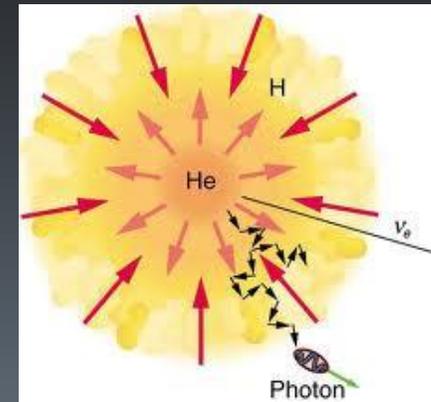
Ability to get through classically forbidden barriers



Light/Matter acting as a wave

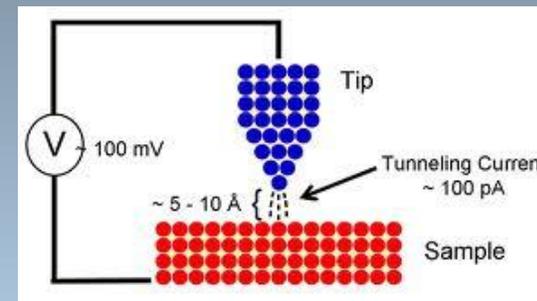
Quantum Tunneling

Photon tunneling

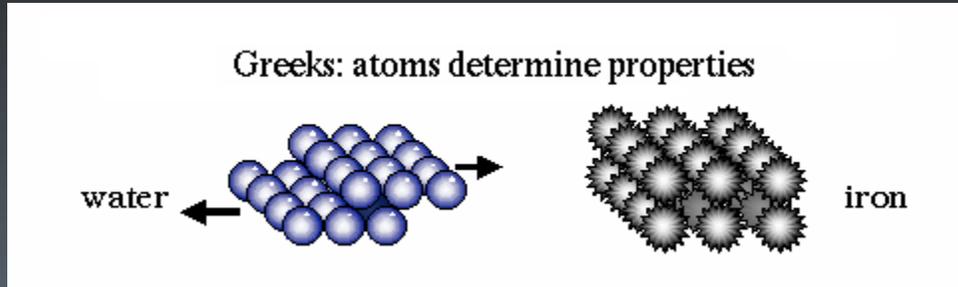


Radioactive Decay

Scanning Tunneling Microscope

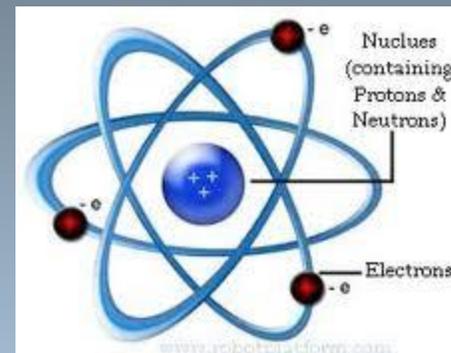
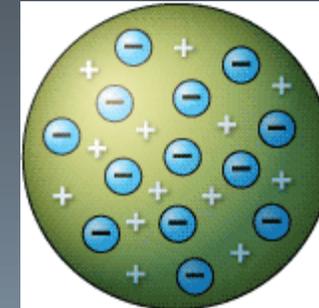


The Atom



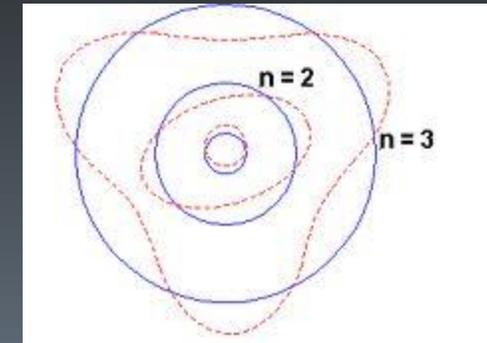
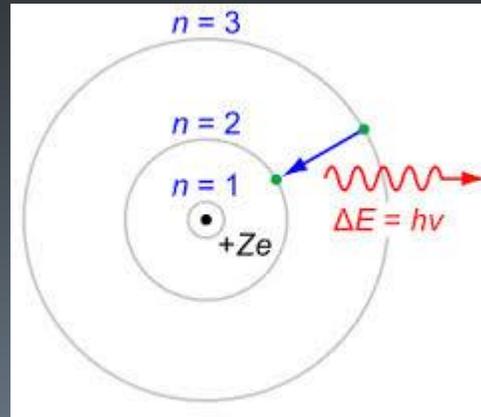
Democritus, 460 BC
Indivisible bit of matter

J.J. Thomson, 1897
Electron – Cathode Ray tube
Plum Pudding Model



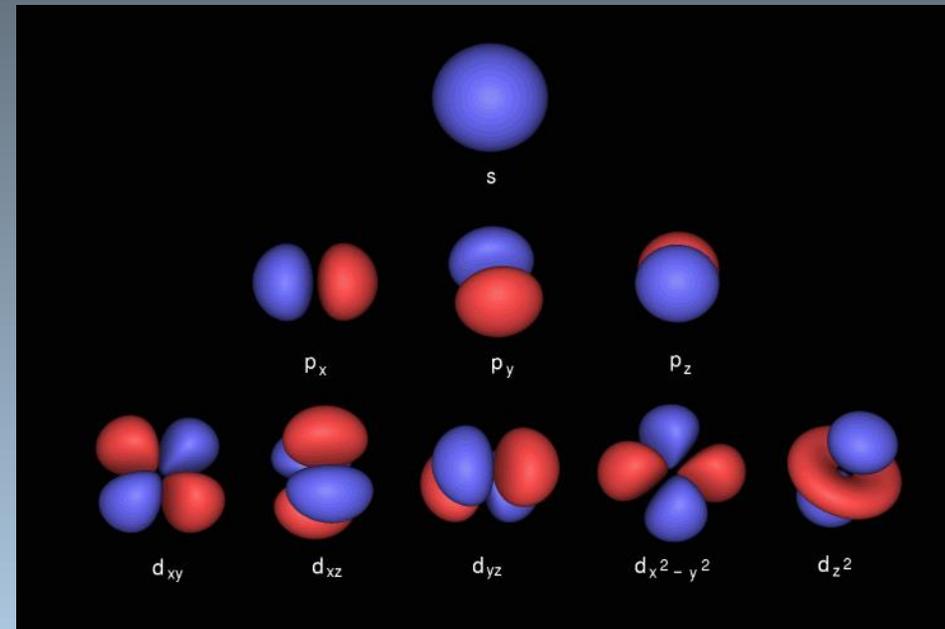
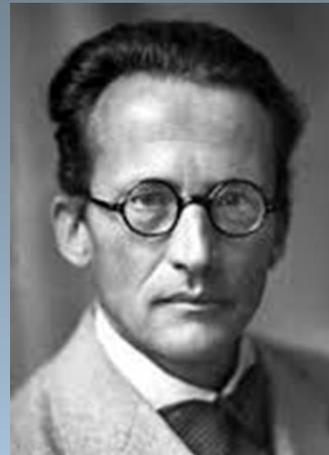
Rutherford, Early 1900s
Alpha rays on gold foil
Model having nucleus

Quantum models of atoms

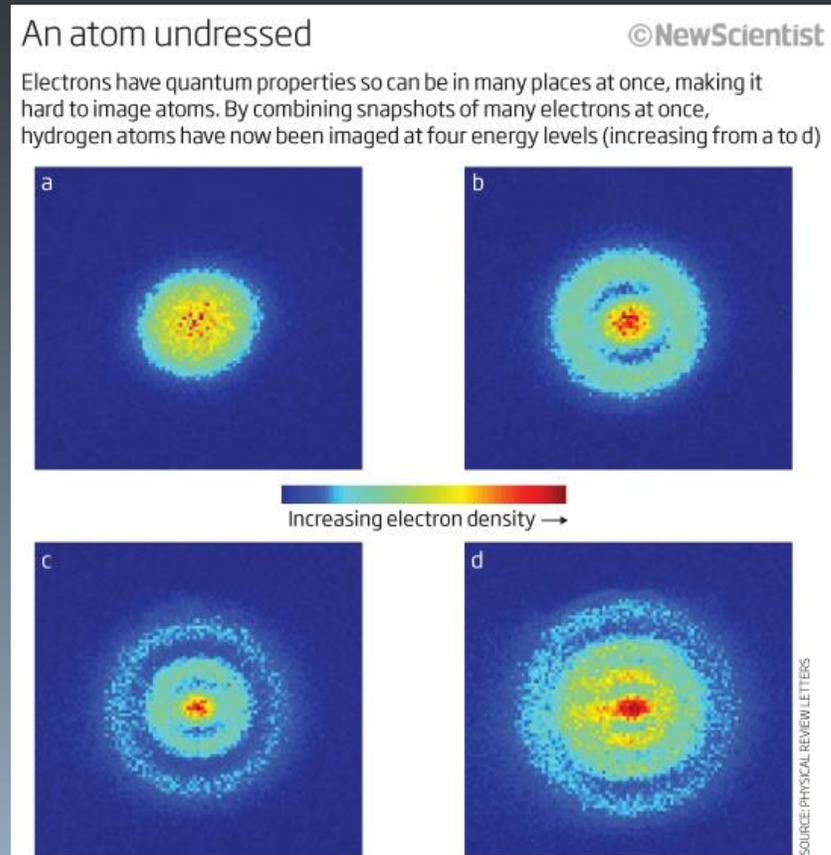


The standing de Broglie waves set up in the first three Bohr orbits.

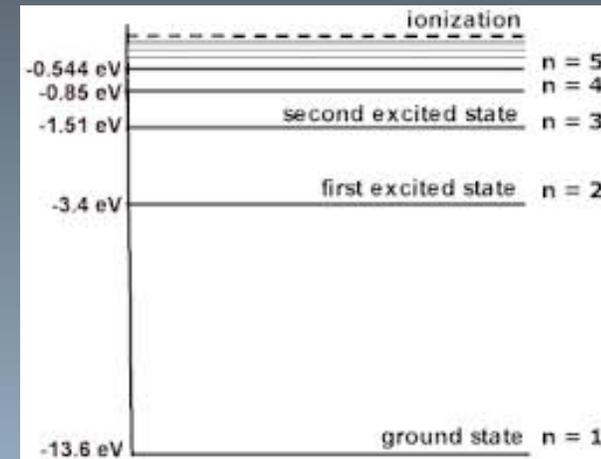
Schrodinger's
description



Hydrogen atom energy levels



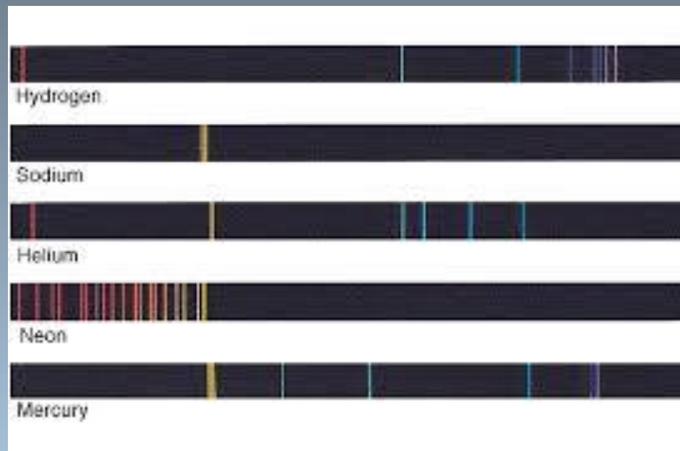
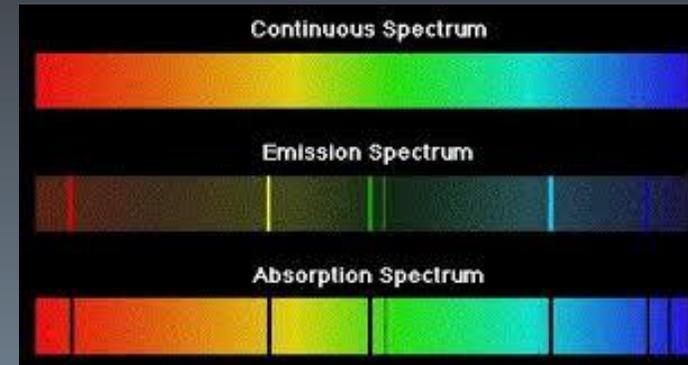
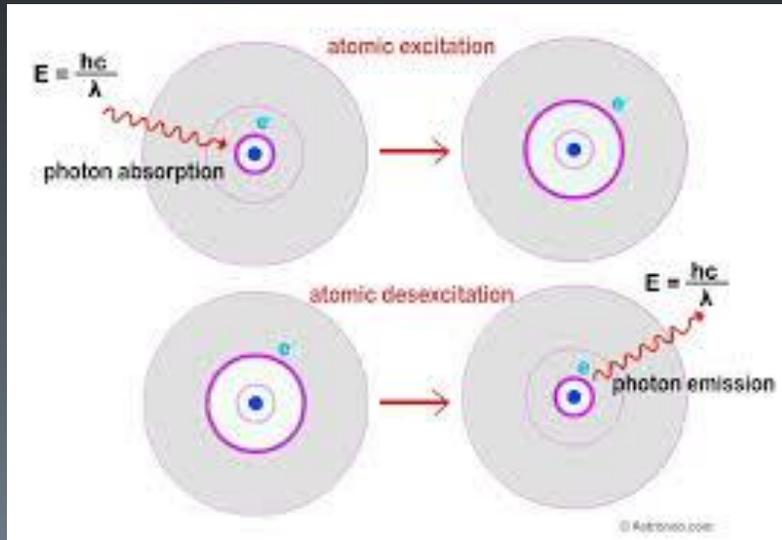
$$E_n = -\frac{13.6 \text{ eV}}{n^2}$$



Different atoms have different energy levels

1 electron-Volt (eV) =
 1.6×10^{-19} Joules

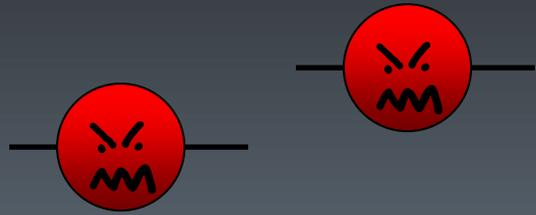
Atoms and light



Each atom/element has its
fingerprint spectrum
Light from stars!! Much more!!

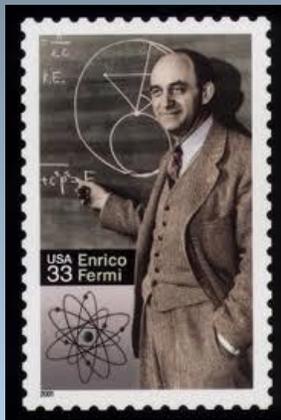
Atomic spectra

Two kinds of quantum particles



Fermions

Electron, proton, etc
Exclusion



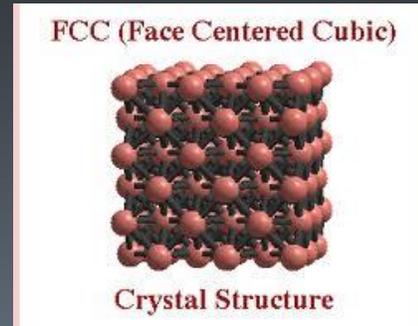
Bosons

H atom, photons, etc
(also, even # of fermions)
'Communal'



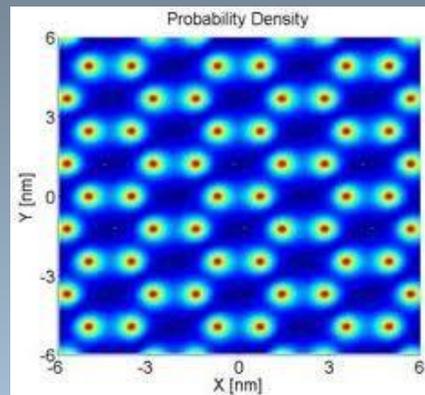
Atoms and crystals

E.g. Copper



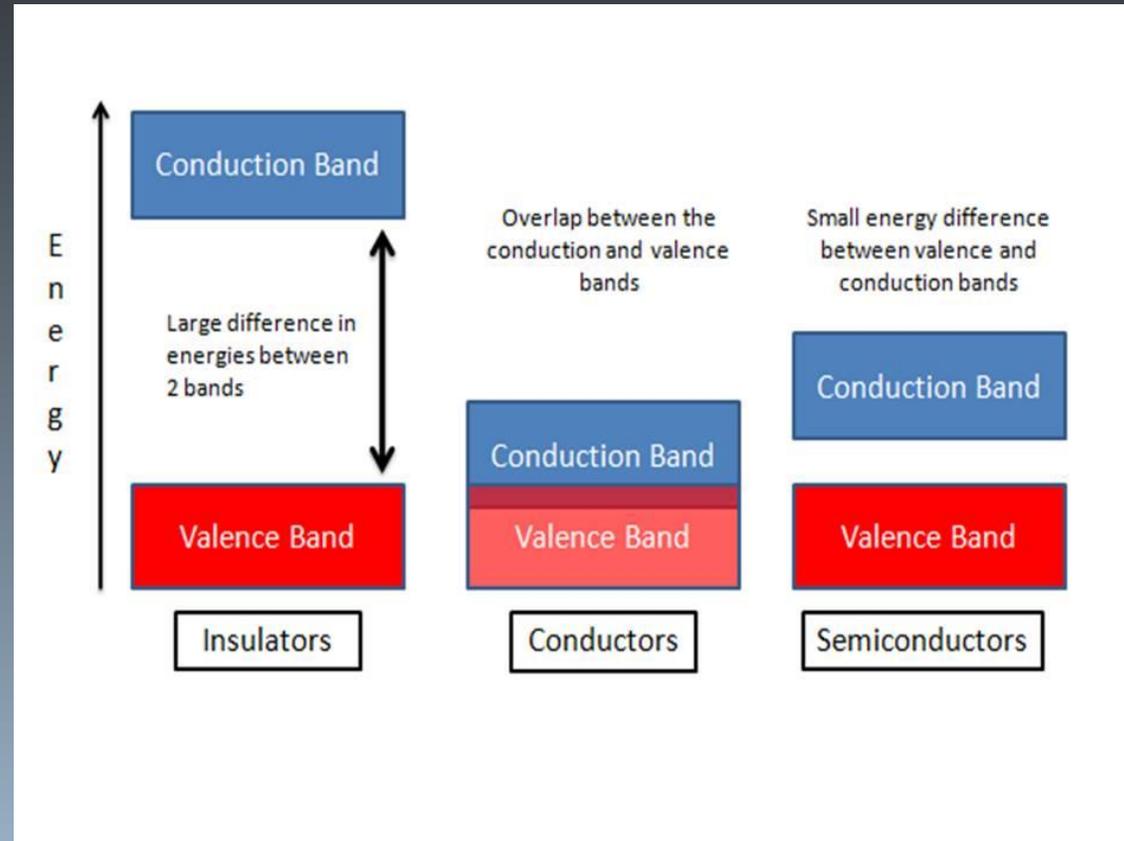
Crystal

In some materials, electrons can hop from atom to atom



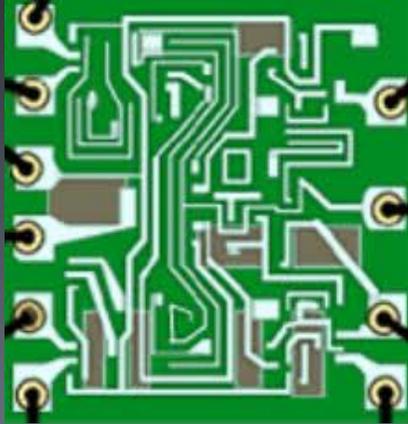
Several states with energies very close

Conductors, semi-conductors, insulators



'Hopping' electrons occupy lowest energy states

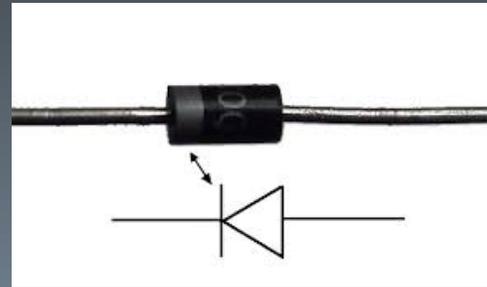
Current electronics



and much more.....

Diodes and Transistor

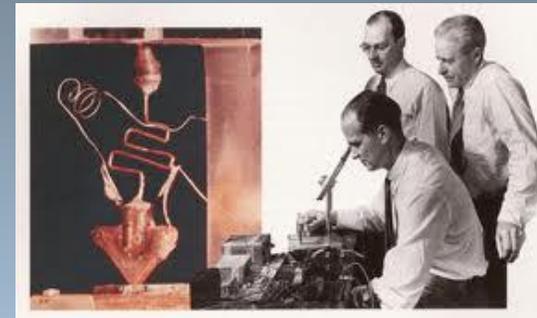
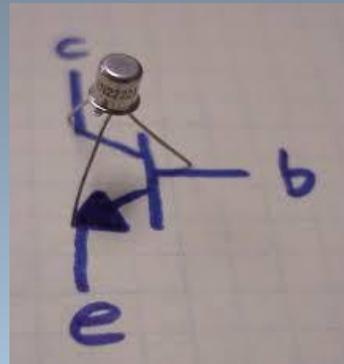
Based on combining semiconductors having different band gaps



Diode:
one-way current

**Transistor: amplifies
signals
(Valve analogy)**

Transistors



**1947: Shockley, Bardeen,
Brattain**

Bosons – friendly behavior



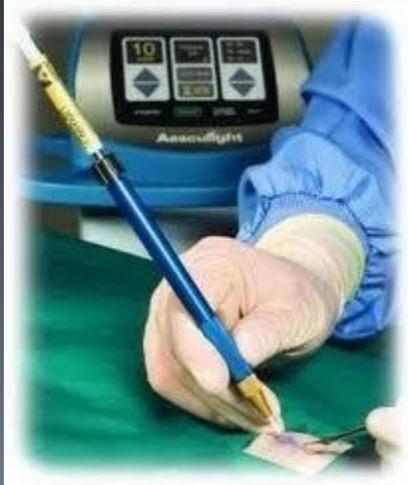
Laser

Light Amplification by Stimulated Emission of Radiation



Laser Cap

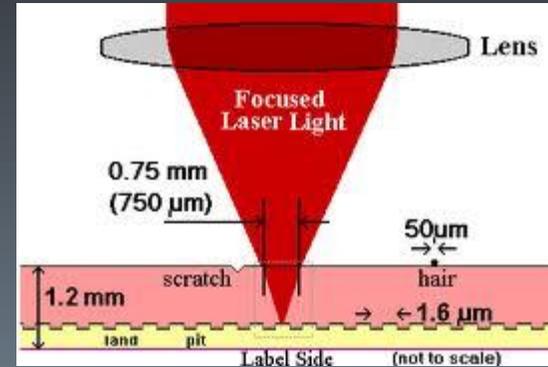
Laser application



Surgery



Barcoding

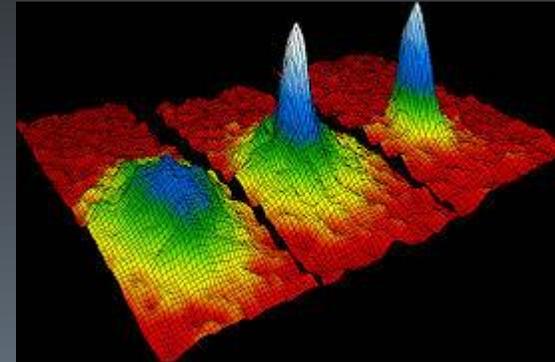
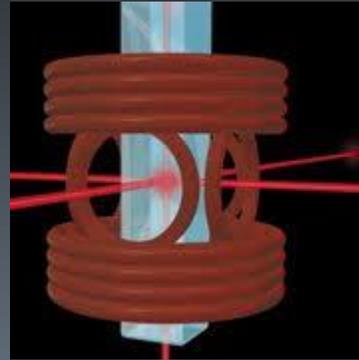
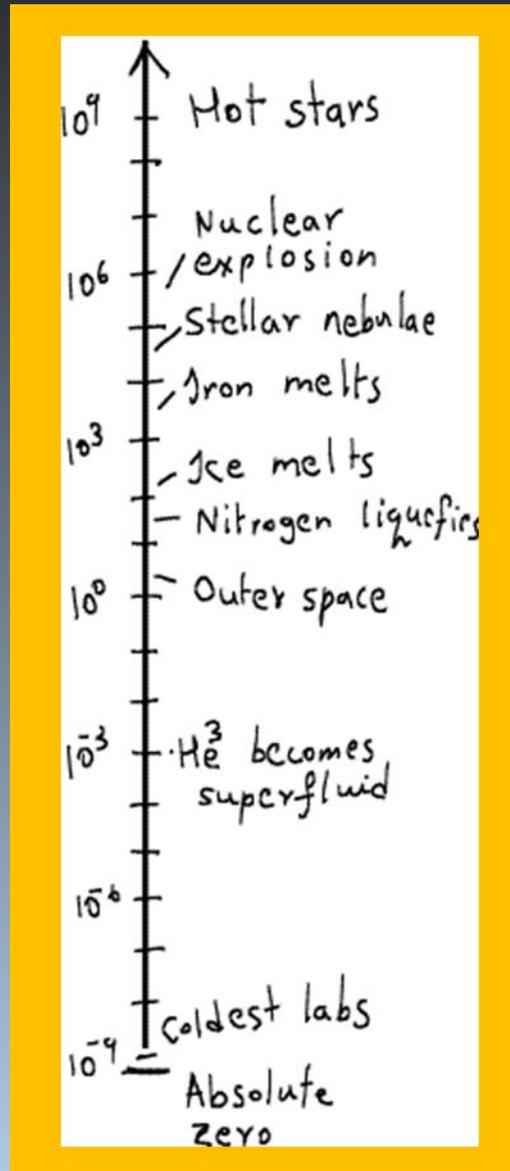


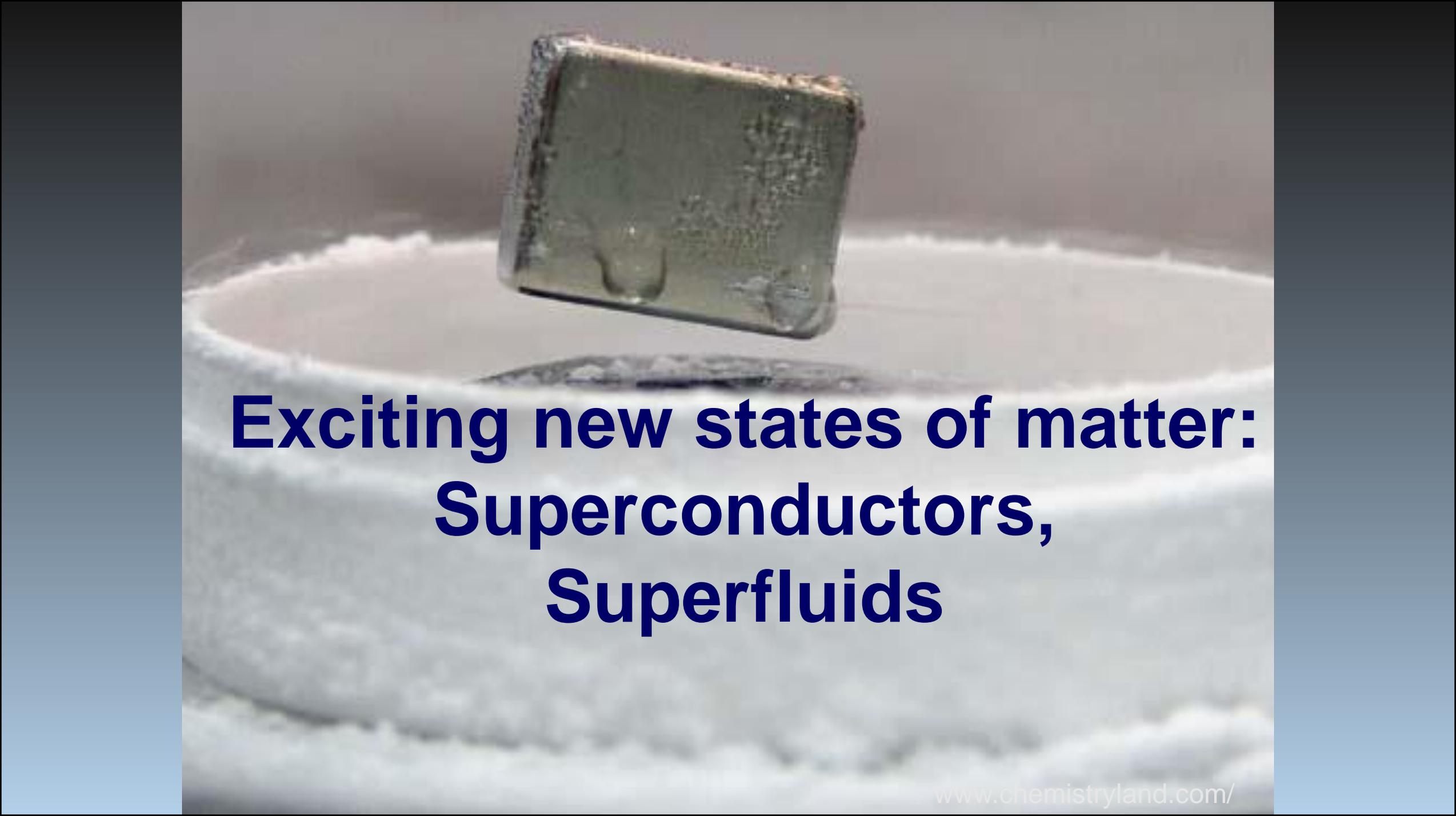
Optical disc drive
CD/DVD

Controlled fusion, and more.....

Laser-Speaker

Bose-Einstein condensation

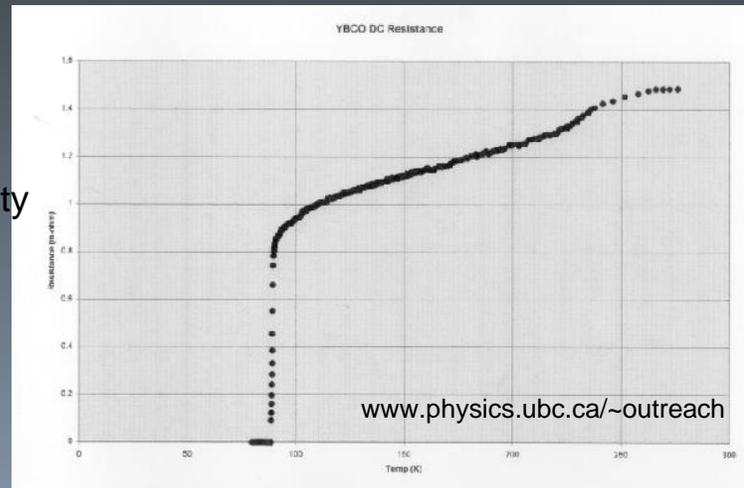


A photograph showing a rectangular, dark, metallic-looking piece of a superconductor levitating above a white, frothy liquid nitrogen bath. The piece is suspended in the air, demonstrating the Meissner effect. The background is a plain, light-colored surface.

**Exciting new states of matter:
Superconductors,
Superfluids**

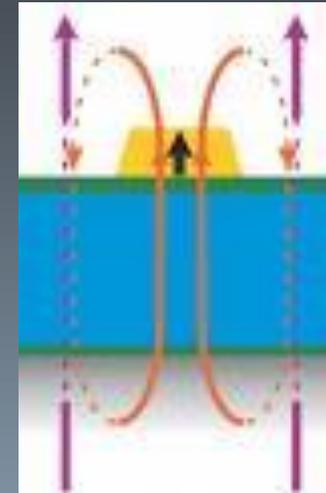
Properties of Superconductors

Resistivity



Temperature

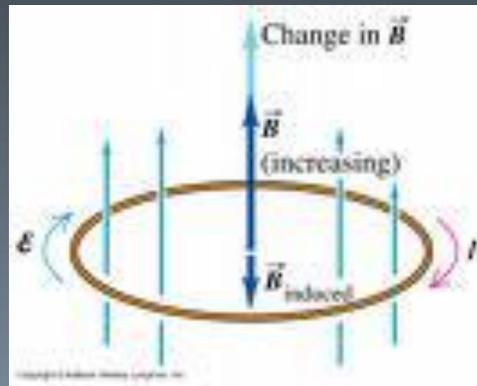
Zero Resistance
("Friction free")



Focus.aps.org

Repels magnetic fields
("Perfect diamagnet")

Currents and Magnetic Fields



A changing magnetic field can induce a current in a wire

E.g. AC power supply

The induced current opposes the magnetic field

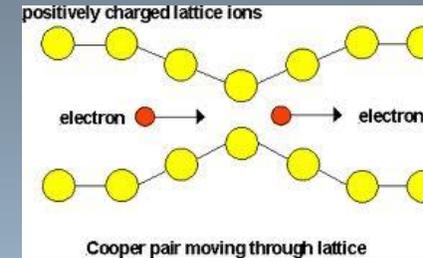
Lowering temperature lowers the resistance of metals.

Understanding Superconductivity

“Bardeen-Cooper-Schrieffer theory”:
Cooper pairs are the key!



Bardeen and the quad



[The Cooper Pair Dance](#)

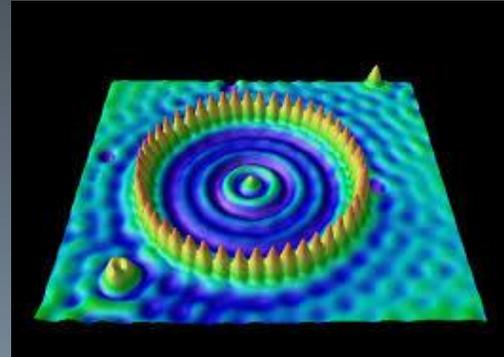
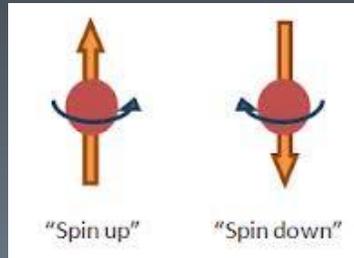
A photograph showing a rectangular metal block suspended in the air above a circular superconductor. The superconductor is covered in a layer of white, frost-like material. The background is a plain, light-colored surface.

Levitation

Superconductors: Perfect diamagnets Levitation

The Quantum World

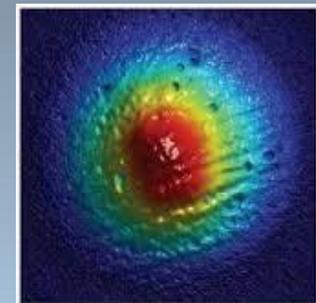
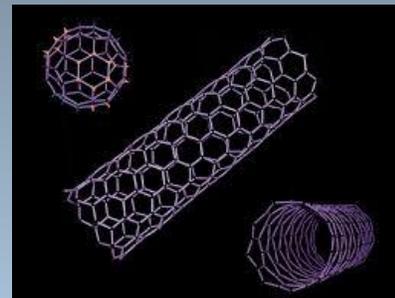
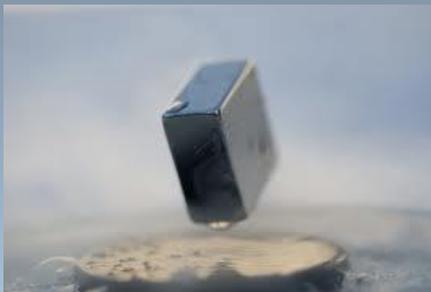
Condensed Matter, Ultra-Cold Atoms



Matter Waves

Quantum superposition
Does God play Dice?

Bizarre States
of Matter



Assignment 1

ASSIGNMENT 1: DREAMING BIG – Due by email to Smitha and Karmela by Feb 2

Thinking through what scientific topics you might want to explore and what projects and collaborations you might want to form; getting started on the creative flow.

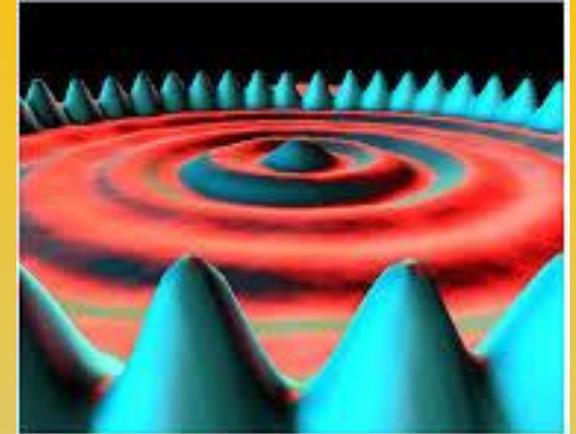
Blurb (minimum 250 words):

Please write down i) a few ideas for what kinds of projects you might be interested in ii) what expertise you can bring in (even if you have to pick it up now), iii) what scientific concepts you would want to focus on, and iv) what components your ideal team would have based on the current talent (e.g. physics expert on .., music creator, costume designer, etc).

Creative fragment (spend a minimum of 15min):

Imagine you were to start what you propose above, play with it, and record what comes out. Maybe a sketch, points for a story, an audio clip, an installation, a description of some physics/science that inspires you, be it through words or equations..... There are no constraints on the medium (bring it to the next class if you can't send by email, but mention what it will be in your email).

Quantum Voyages



$$H\psi = E\psi$$



Latrelle Bright

Synopsis: Guided by Sapienza, the spirit of knowledge, two voyagers enter the microscopic realm of everyday human experience. As in epic and fairy tales, the voyagers explore land after land, each tickling the viewer's imagination and, unlike fairy tales, offering glimpses of a world we believe actually resides around us. The trio confront terrifying prospects of being Dead and Alive at once, encounter electrons acting as waves, are pelleted by photons, glide through diaphanous orbitals of atoms, precess in Magnetic Resonant Imaging machines, levitate above superconducting surfaces, and navigate disordered quantum within us and the affirmation that things are never what they seem.



AUDITIONS

for

Quantum Voyages

*A new performance piece by
Smitha Vishveshwara and
Latrellle Bright*

TUESDAY, JANUARY 30, 2018

**Physics Interaction Room
Loomis, 204
7:00-9:30**

*No need to memorize. Everyone will read from the script. Wear comfortable clothing.

We hope to see you there!

For more info contact smivish@illinois.edu

GENERAL REHEARSALS

- Tuesdays and Thursdays from 7:00p – 9:30p, Thursday, February 1 – March 22
- One additional rehearsal to be determined based on cast availability

TECH REHEARSALS

- Tuesday, Wednesday, Thursday, March 27-29 from 7:00-10p

PERFORMANCES

- Friday, March 30, 2018 at Sir Tony Leggett's 80th birthday, iHotel in Champaign
- Wednesday, April 4, 2018 at The Beckman Institute
 - This performance will require a pick-up rehearsal on April 3, 2018