The Weird World of the Very Very Small

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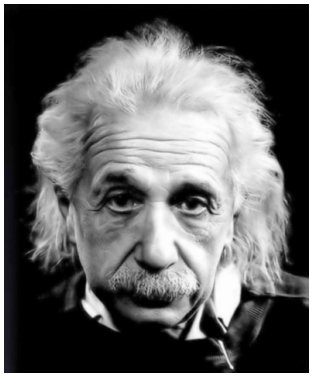
HWKU3A 25 Mar 2022

Introduction



" Everything should be made as simple as possible, but not simpler "

Introduction

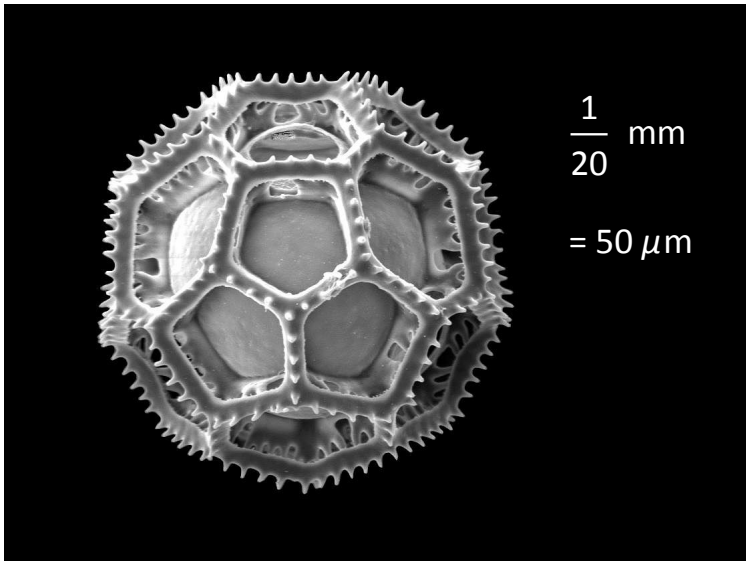
A Sense of Scale
Metres → Nanometres

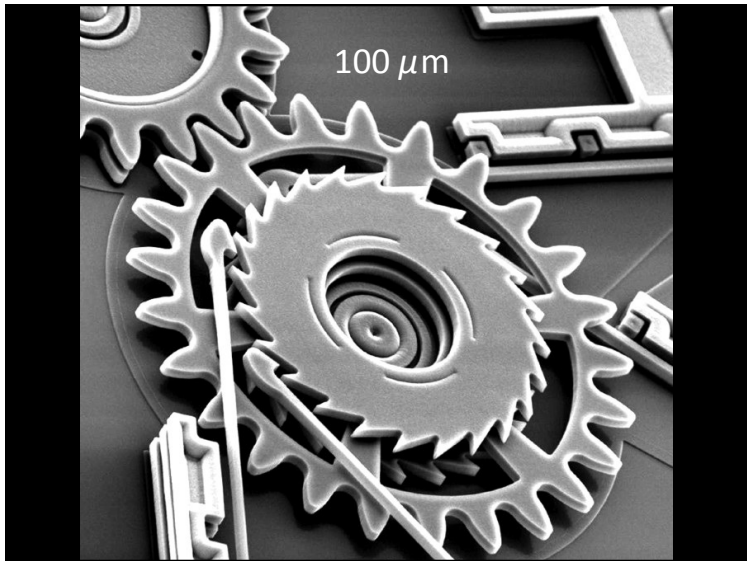
A Sense of Symmetry
Underlying Structure

The Quantum World
Seeing Atoms

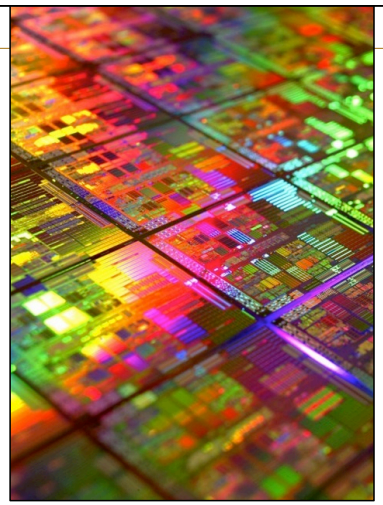
A Sense of Scale

The Weird World of the Very Very Small





A Sense of Scale



Microprocessor chip area ~ mm^2 …

10 million transistors…

so size of components ~ 10–100 nm

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Structure Within

- What is the world made of?
- How can we tell?
- What clues do we have?

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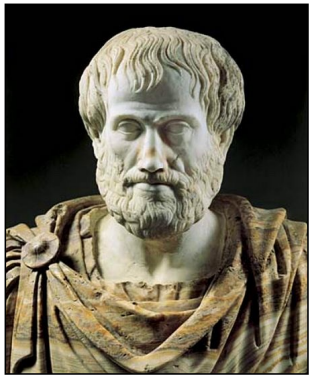
Aristotle



Elements

Fire
Air
Water
Earth

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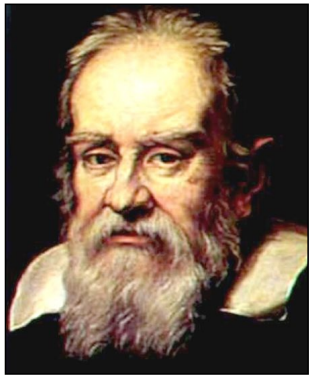
Galileo



The nature of the world around us should be determined by quantitative experiments, not by qualitative intellectual arguments

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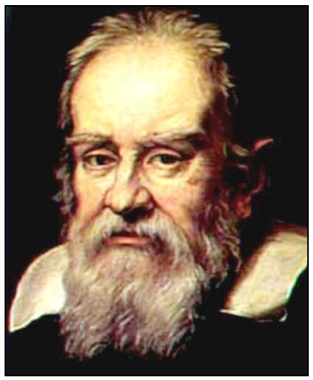
Galileo



Ask not

"What should happen if… ?"

but

"What actually happens if… ?"

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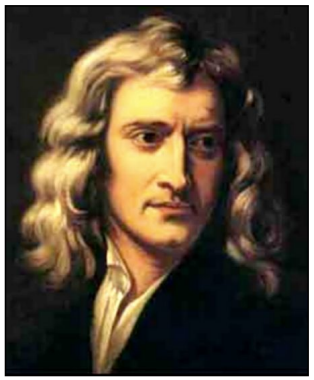
Newton



Laws of Motion

Law of Gravity

Nature of Light

"Classical Mechanics"

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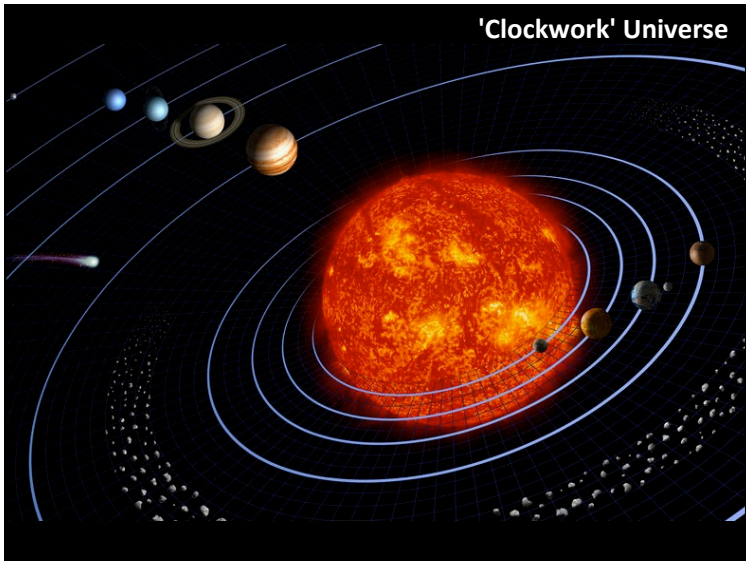
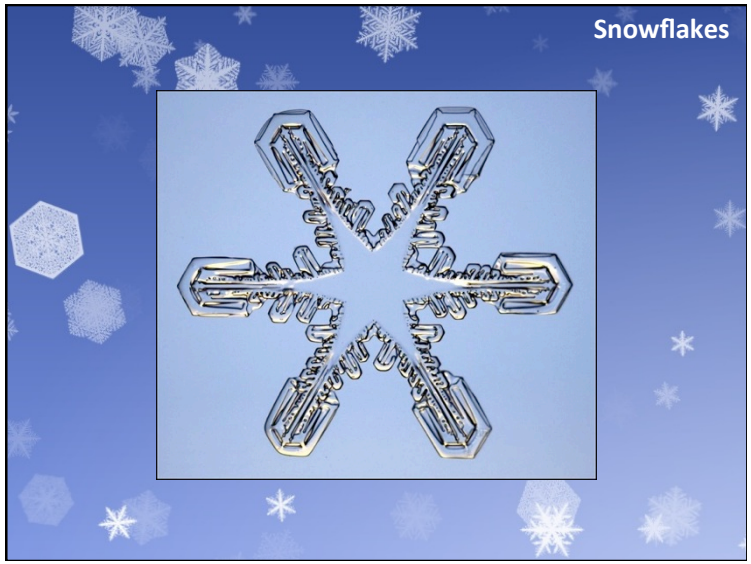
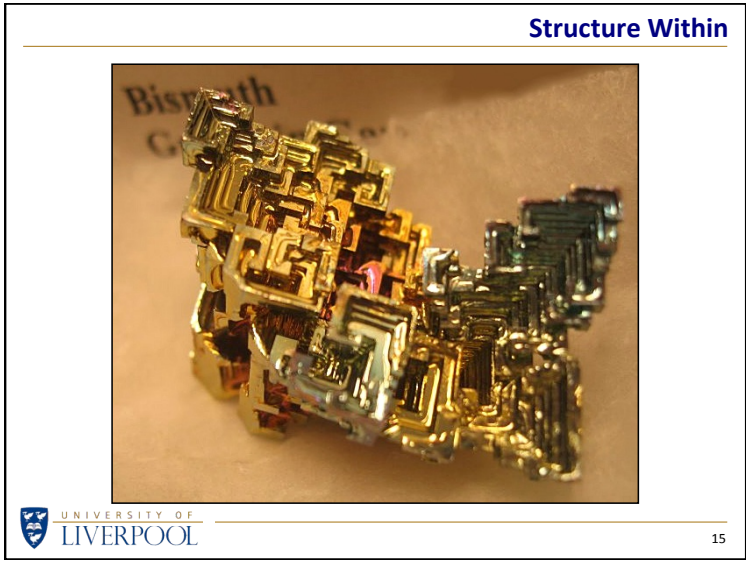

'Clockwork' Universe


Snowflakes


Structure Within
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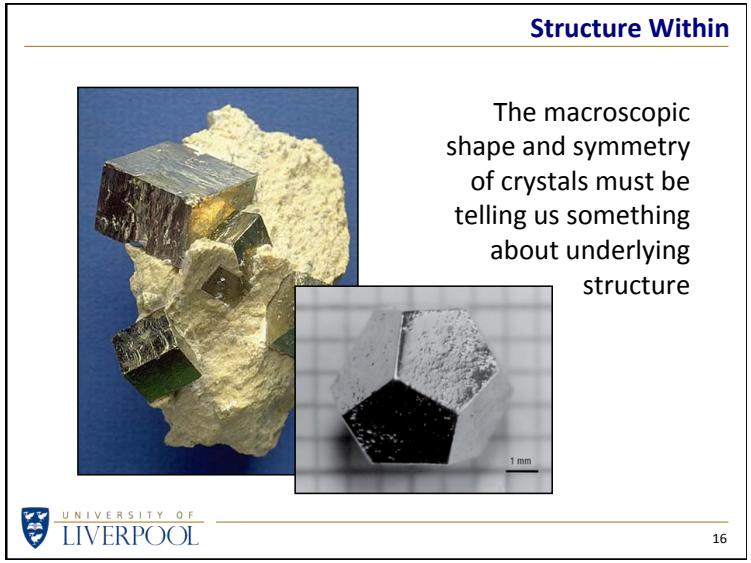
Structure Within
The macroscopic shape and symmetry of crystals must be telling us something about underlying structure
1 mm
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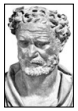
Atoms

1600 1700 1800 1900

Democritus 


Boyle


Newton


Lavoisier

Dalton 


Avogadro

Maxwell 


Boltzmann

Particles and Waves

1800 1850 1900


Young


Thomson

^ Light (Waves)

^ Electrons (Particles)

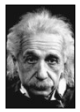
Atoms To Quantum Mechanics

1900 1910 1920 1930

Becquerel 

Rutherford 


Planck


Einstein


Bohr

deBroglie 

Heisenberg 


Schrödinger

^ Radio-activity

^ Light (Particles)

^ Atoms

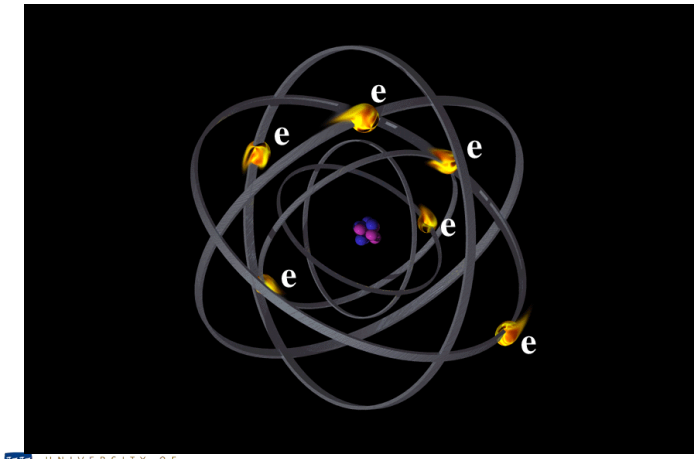
^ Atomic Nucleus

^ Prob-ability

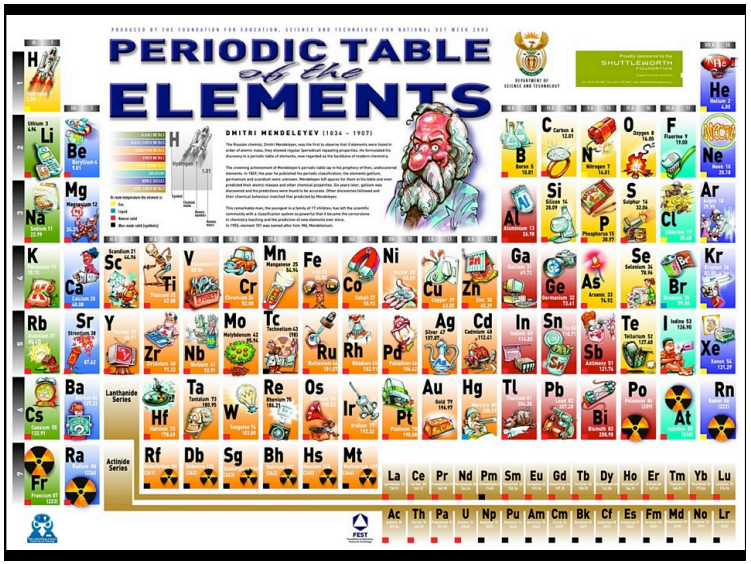
^ Electrons (Waves)

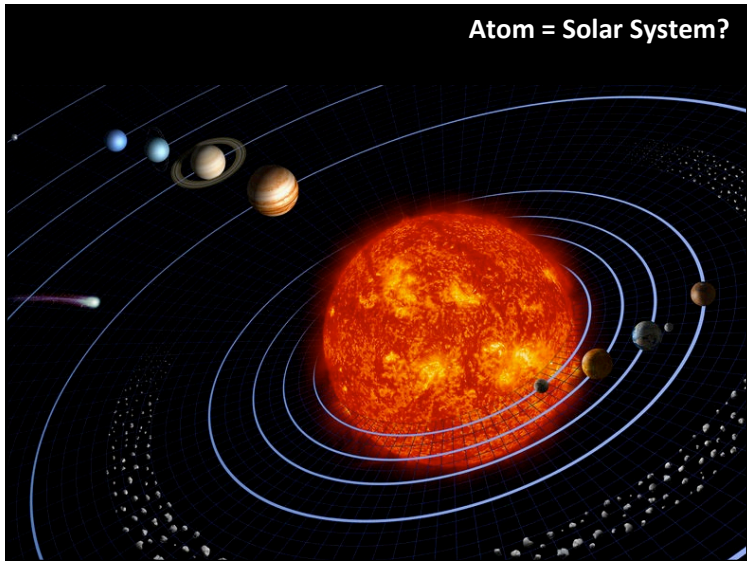
^ QM

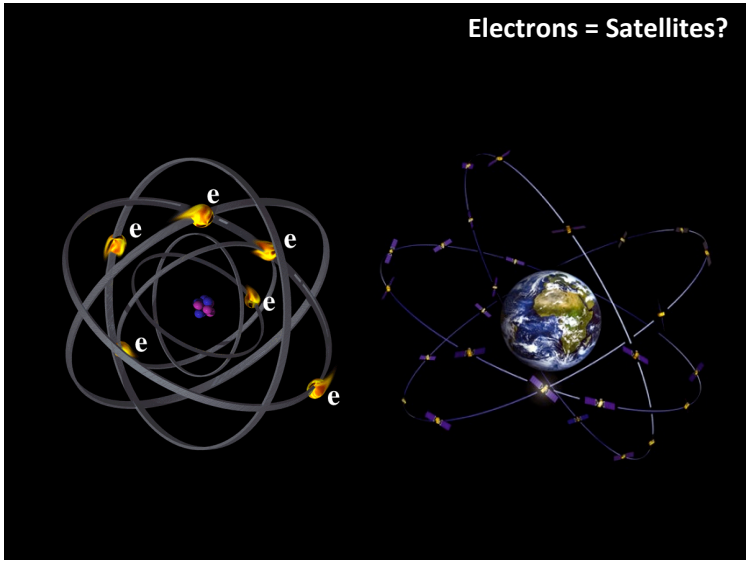
Bohr Model

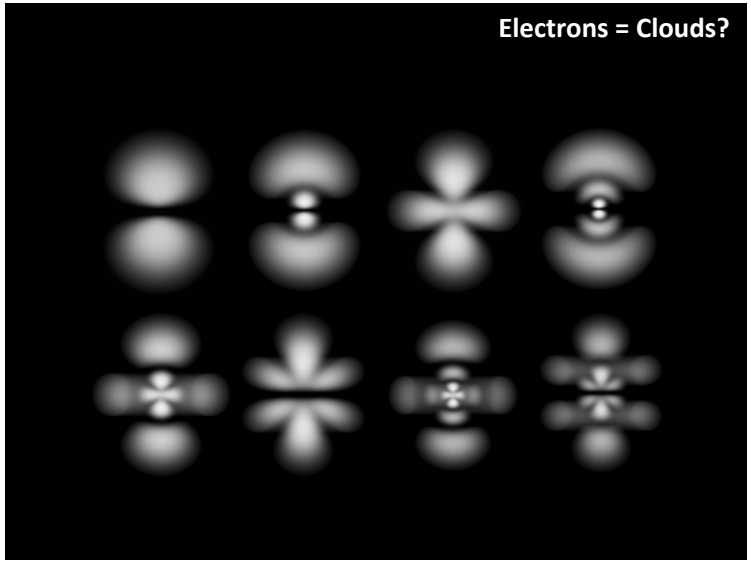


The Weird World of the Very Very Small









Dealing With Atoms

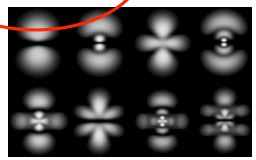
Particles
Waves
Orbits
Spin
Energy

Words

Pictures

Maths

$H\psi = E\psi$



Heisenberg

" We wish to talk about the structure of atoms. But we cannot talk about atoms in ordinary language "

Dealing With Atoms

Would it be better to use words that don't carry any 'baggage', or preconceptions?

Rather than say…

" The electrons orbit and spin in the atom "

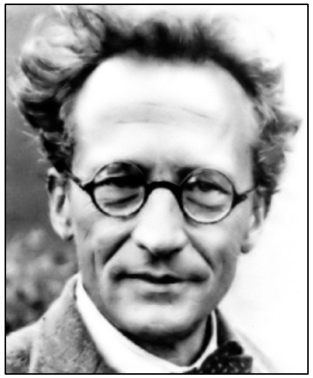
Would it be better to say…

" The slithy toves did gyre and gimbal in the wabe "

Bohr

" Everything we call real is made of things that cannot be regarded as real "

Schrödinger



" Atomic physics has shown that atoms have no meaning, but can only be understood in experimental measurement "

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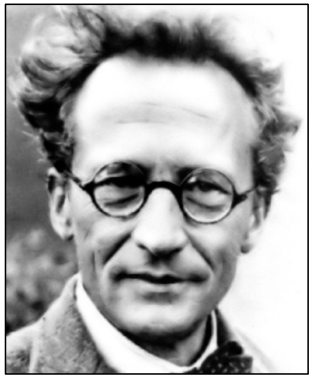
Schrödinger



" I don't like it, and I'm sorry I ever had anything to do with it "

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QM vs Common Sense

Atoms (indeed, all particles) are unpredictable
We can know only the ***probability*** of an atom having a particular position, speed, energy, …

Atoms do not have a finite size
An electron 'in' an atom could be ***anywhere***

Atoms can be in two states at the same time
Electron 'spin' can be simultaneously clockwise ***and*** anticlockwise

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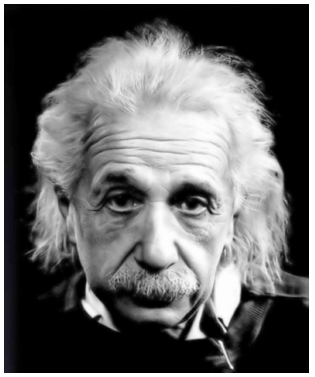
Einstein



" Common sense is the collection of prejudices acquired by age eighteen "

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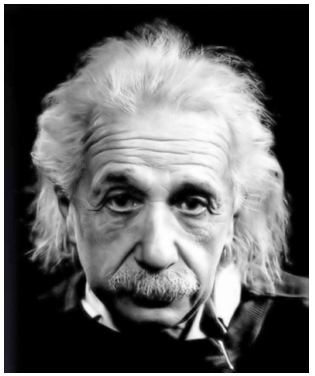
Heads or Tails?

Einstein



" God does not play dice "

" God is subtle but he is not malicious "

Bohr

" Stop telling God what to do! "

Three Aspects of QM

- Order matters
- Schrödinger's Cat
- Using QM to see atoms

Order Matters

In algebra

$A \times B = B \times A$

In Quantum Mechanics

$A \times B \neq B \times A$

So what?

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If Order Matters




Top pair : carnivores

Bottom pair : veggies

Left pair : 4 legs

Right pair : wings

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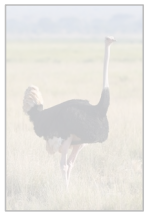
If Order Matters



Pick 2 out of the 4

For instance, pick the **veggie** animals

From these, pick again

For instance, pick the **4-legged** animals

You're left with waterbuck **and** lion!

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If Order Matters




If we had picked in a different order…

First pick the **4-legged** animals

Then pick the **veggie** animals

You're left with waterbuck **and** ostrich!

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Schrödinger's Cat

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How Do We Know QM Is Right?

- So far, nothing has proved it wrong
- Quantum Mechanics predicts results that are impossible by 'Classical Mechanics'
- Using QM theory, we can build a microscope that can 'see' atoms

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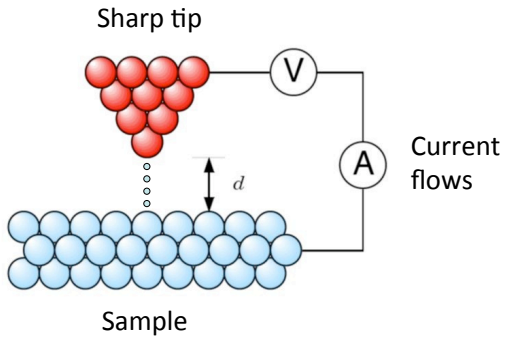
Scanning Tunnelling Microscope



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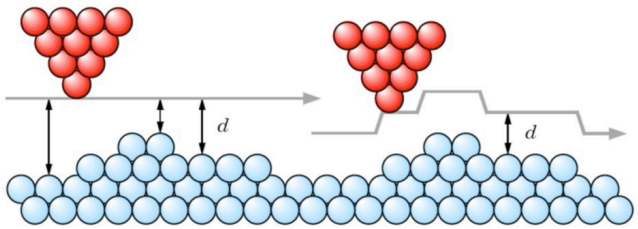
STM

Move tip across sample…



…measuring current at each point

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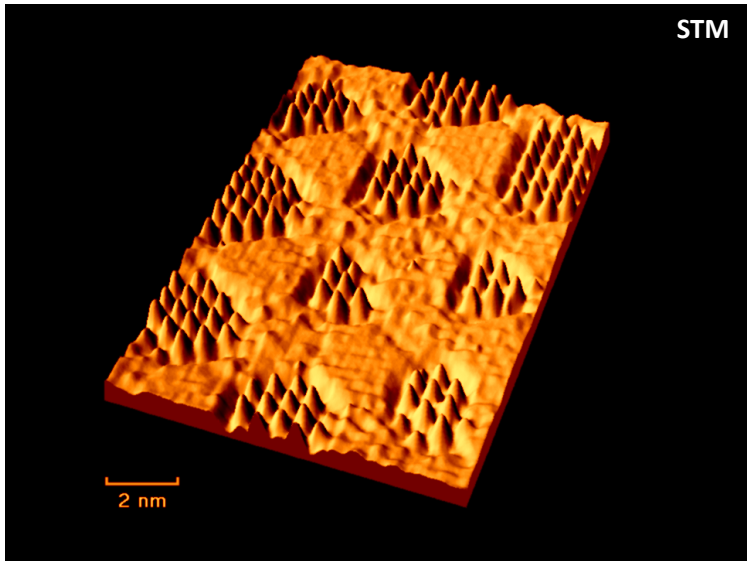
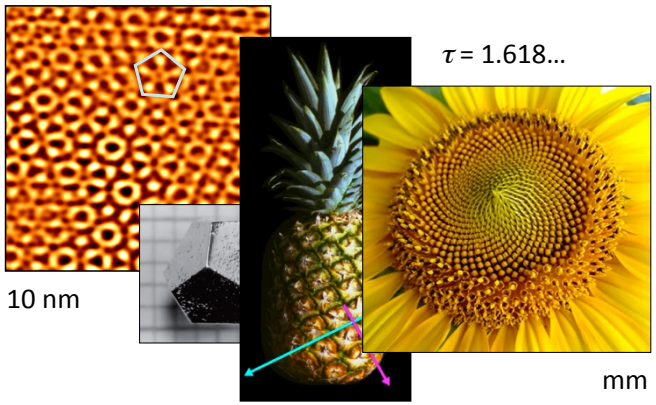
Surface Science

The STM is sealed inside an ultra-high vacuum vessel (10^{-13} atms) to keep it and the sample surface clean.

45



Patterns — Large and Small



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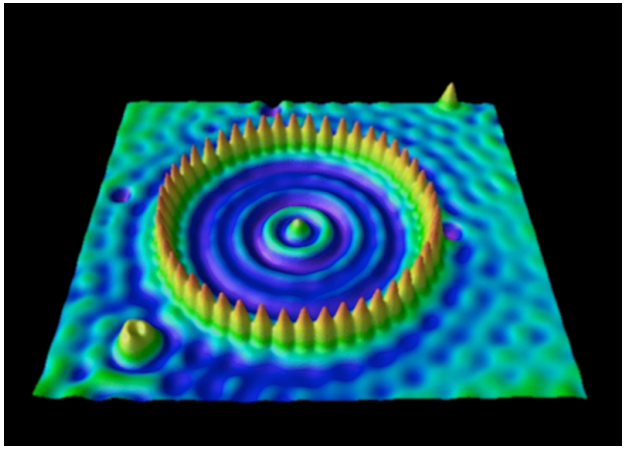
STM of Atomic Corral



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Bohr

" If quantum mechanics hasn't profoundly shocked you, you haven't understood it "

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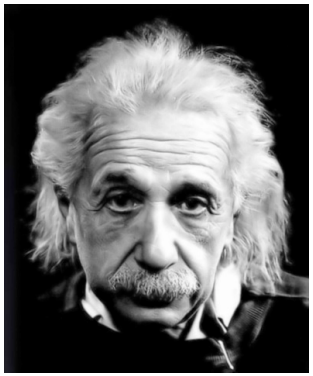
Einstein



" The most incomprehensible thing about the world is that it is comprehensible "

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William Blake

To see a world in a grain of sand

And a heaven in a wild flower,

Hold infinity in the palm of your hand

And eternity in an hour.

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51

The Weird World of the Very Very Small

www.liverpool.ac.uk/~sdb/Talks

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HWKU3A
25 Mar 2022