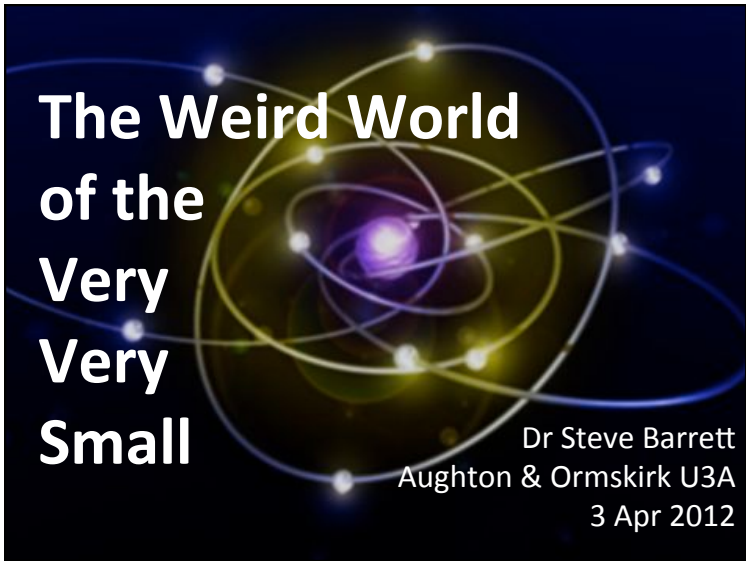


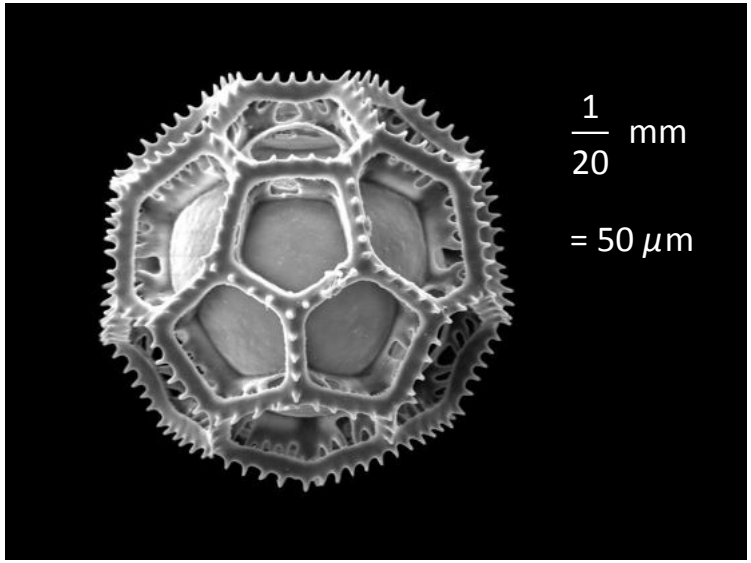
Introduction

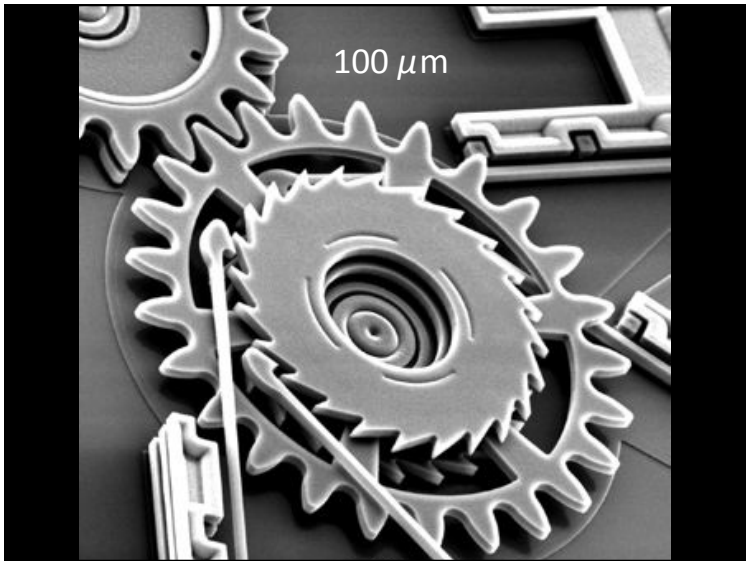
A Sense of Scale
Metres → Nanometres

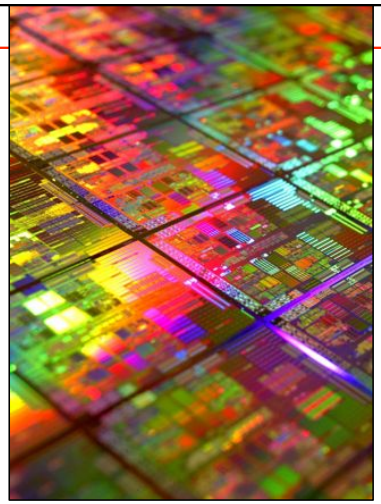
A Sense of Symmetry
Underlying Structure

The Quantum World
Seeing Atoms

The Weird World of the Very Very Small 2







A Sense of Scale

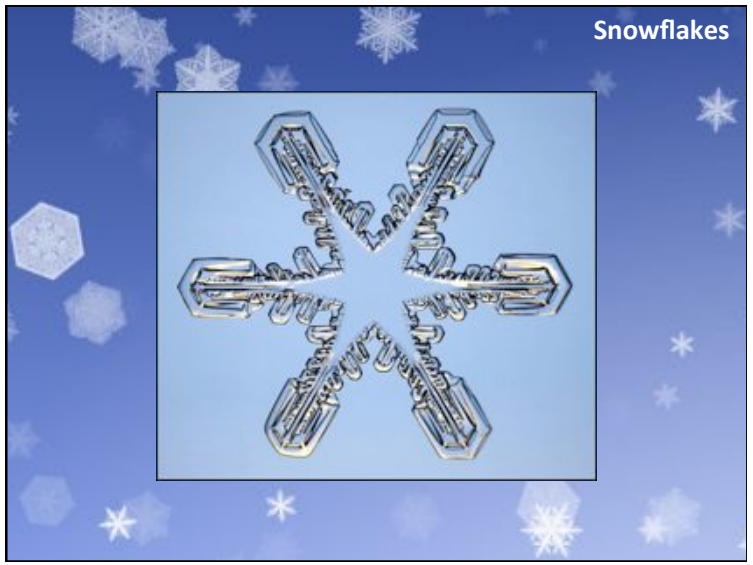
Microprocessor chip area ~ mm^2 …

10 million transistors…

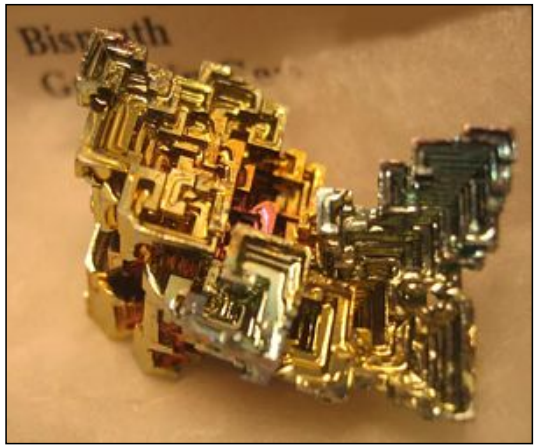
so size of components ~ 10–100 nm

Structure Within

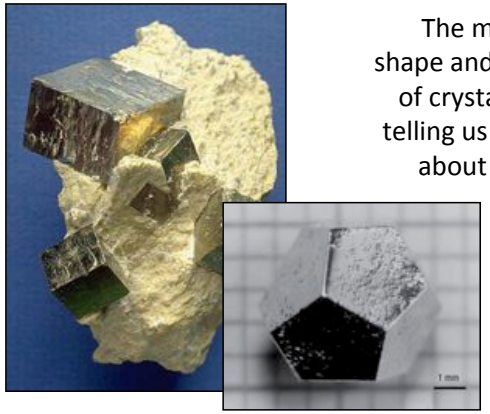
- What is the world made of?
- How can we tell?
- What clues do we have?



Structure Within



Structure Within

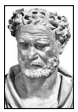


The macroscopic shape and symmetry of crystals must be telling us something about underlying structure

Atoms

1600 1700 1800 1900

Democritus



Boyle

Newton

Lavoisier

Dalton

Avogadro

Maxwell

Boltzmann

Particles and Waves

1800 1850 1900

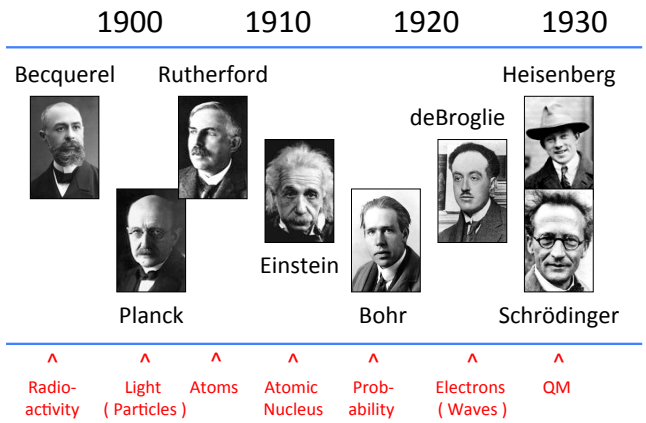
Young

Thomson

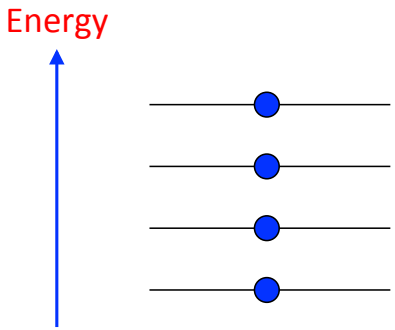
^ Light (Waves)

^ Electrons (Particles)

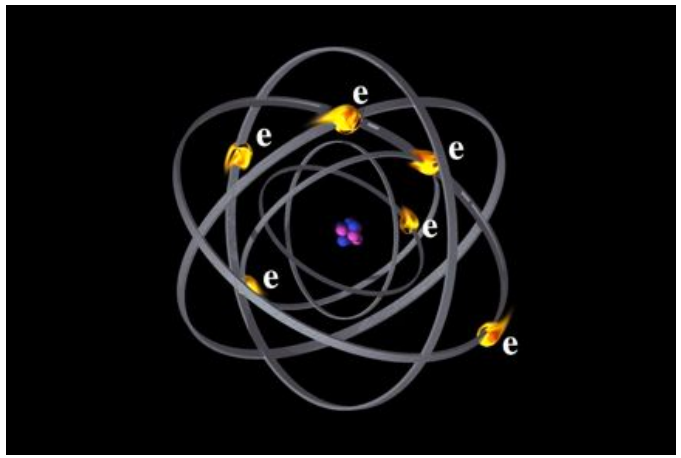
Atoms To Quantum Mechanics

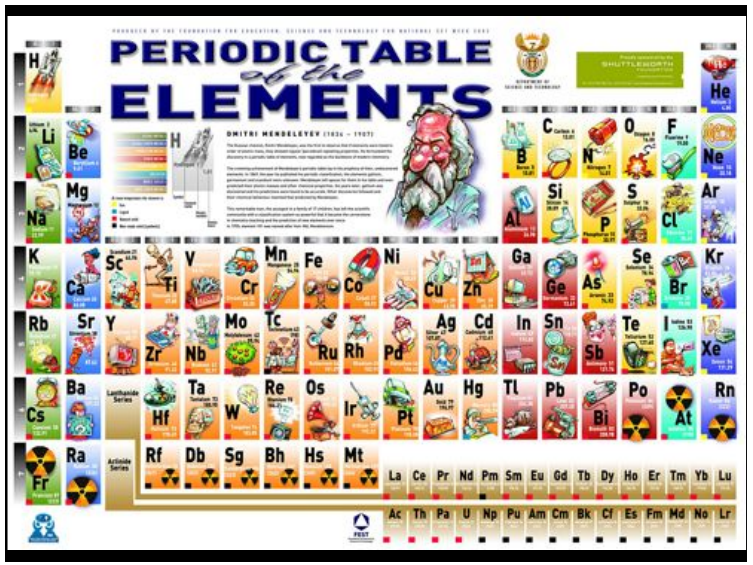


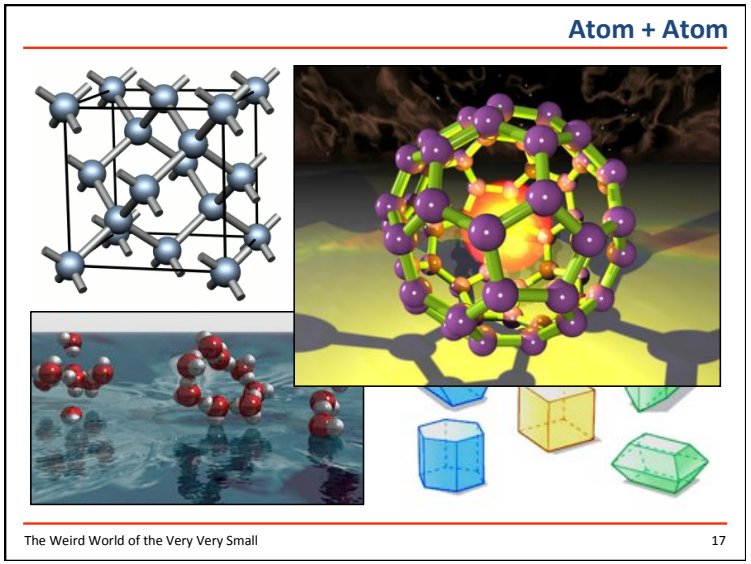
Quantised States

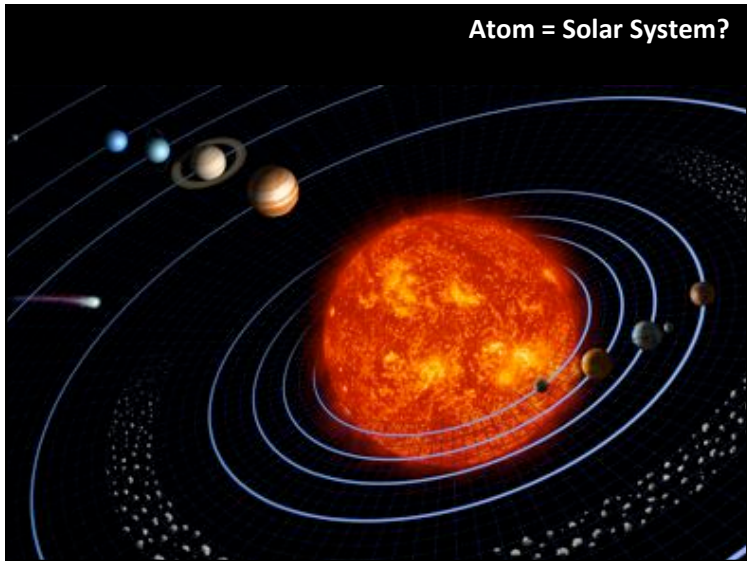


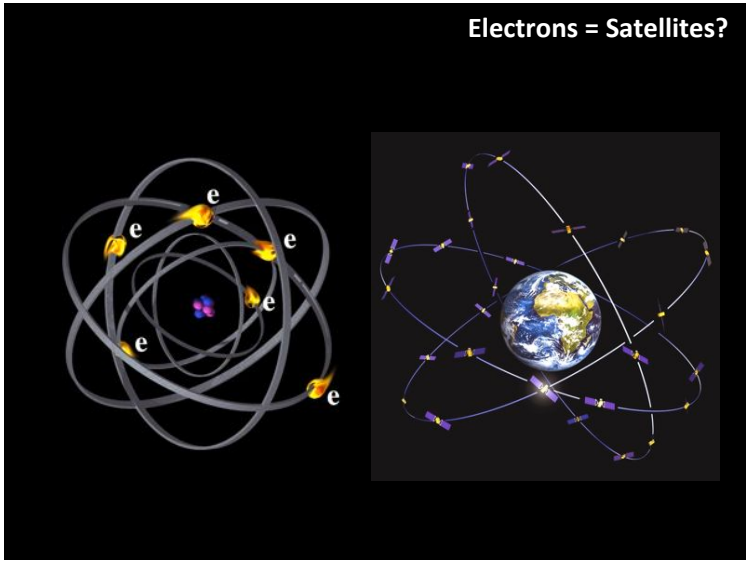
Bohr Model

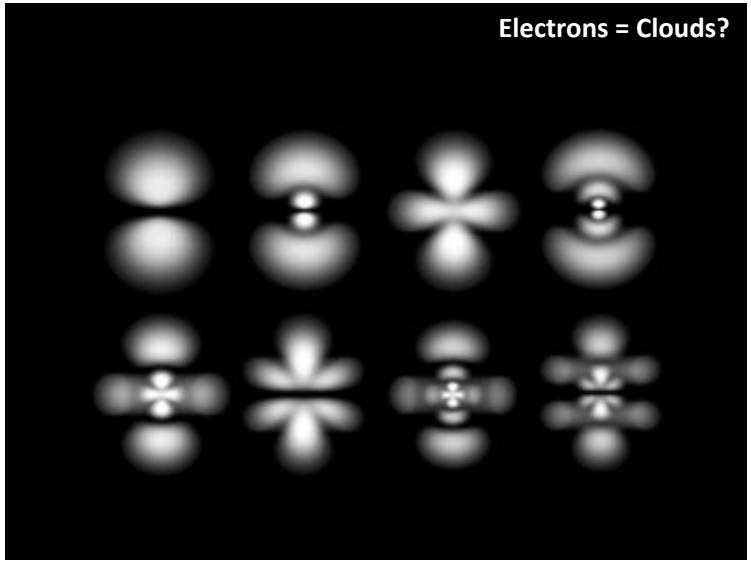





Atom + Atom
The Weird World of the Very Very Small
17


Atom = Solar System?


Electrons = Satellites?
e
e
e
e
e
e


Electrons = Clouds?

Dealing With Atoms

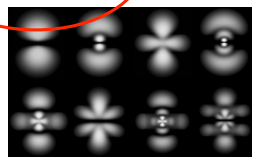
Particles
Waves
Orbits
Spin
Energy

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 "

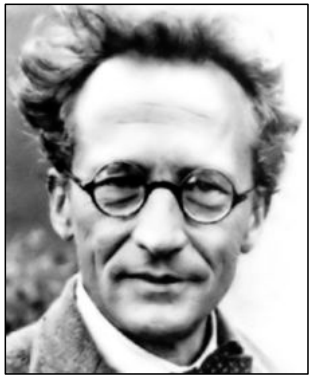
Would it be better to say…

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

Bohr

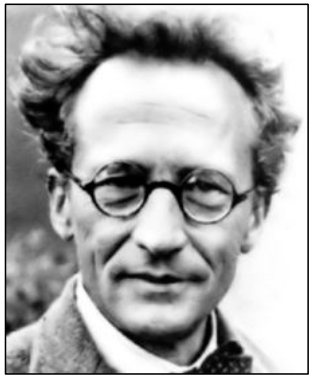
"Everything we call real is made of things that cannot be regarded as real"

Schrödinger



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

Schrödinger



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

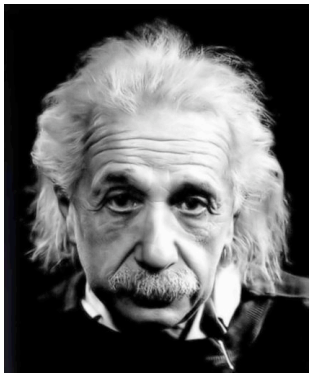
QM vs Common Sense

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*

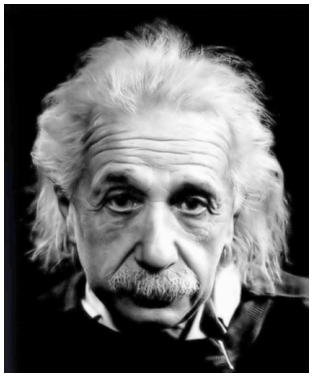
Einstein



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

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?

If Order Matters

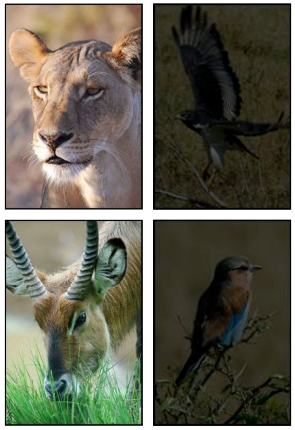
Top pair : carnivores

Bottom pair : veggies

Left pair : 4 legs

Right pair : wings

If Order Matters



Pick 2 out of the 4

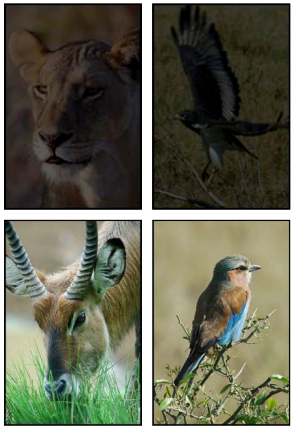
For instance, pick the **veggie** animals

From these, pick again

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

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

If Order Matters



If we had picked in a different order…

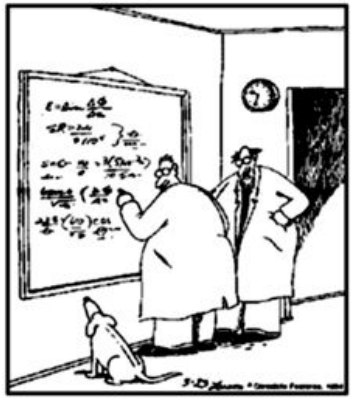
First pick the **4-legged** animals

Then pick the **veggie** animals

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

Schrödinger's Cat

QM and Dogs

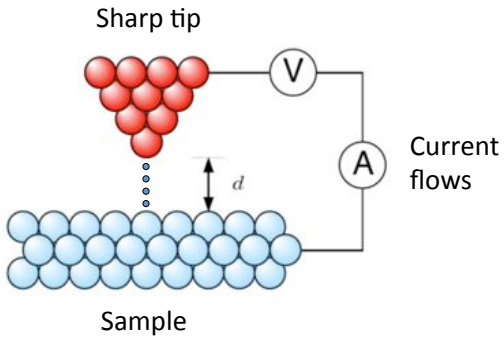


"Ohhh, look at that…
dogs are so cute when they try to comprehend quantum mechanics"

How Do We Know QM Is Right?

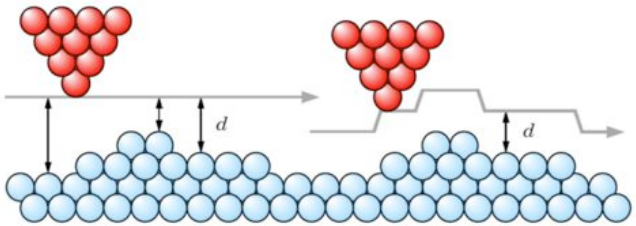
- So far, nothing has proved it wrong
- Quantum Mechanics predicts results that are impossible by 'Classical Mechanics'
- Using QM theory, we can build a microscope that can 'see' atoms

Scanning Tunnelling Microscope



STM

Move tip across sample…

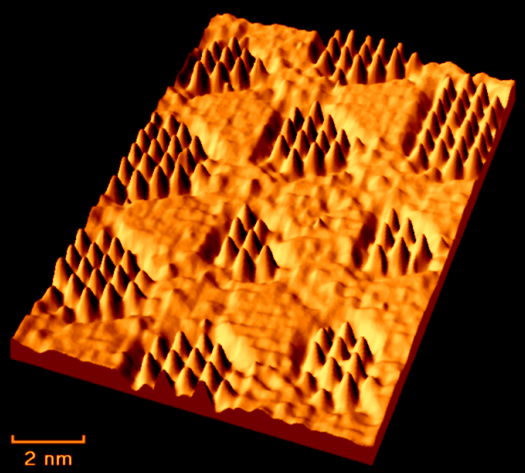


…measuring current at each point

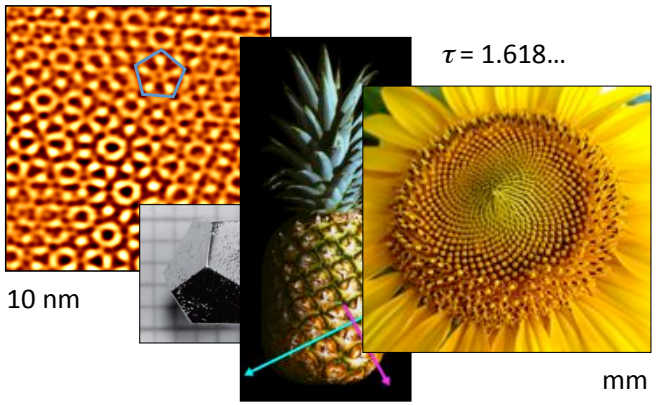
Surface Science

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

STM



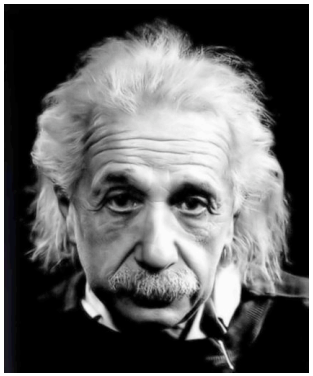
Patterns — Large and Small



Bohr

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

Einstein



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

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.

The Weird World of the Very Very Small

Dr Steve Barrett
Aughton & Ormskirk U3A
3 Apr 2012

http://www.liv.ac.uk/~sdb/ Talks