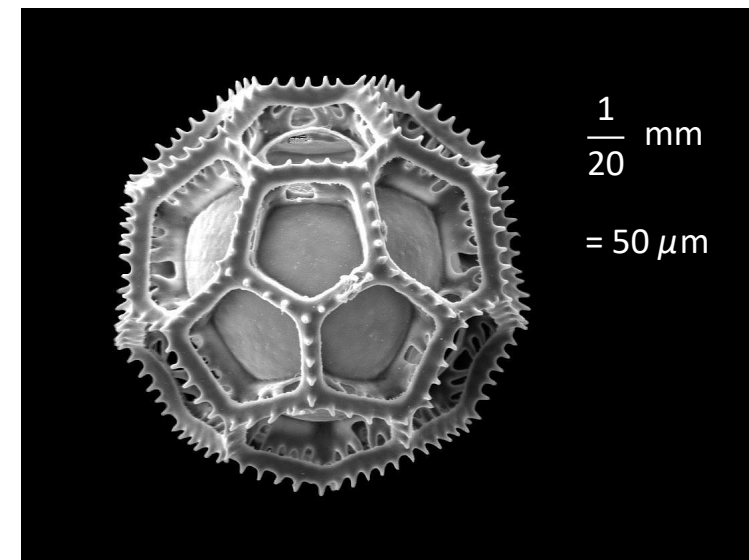
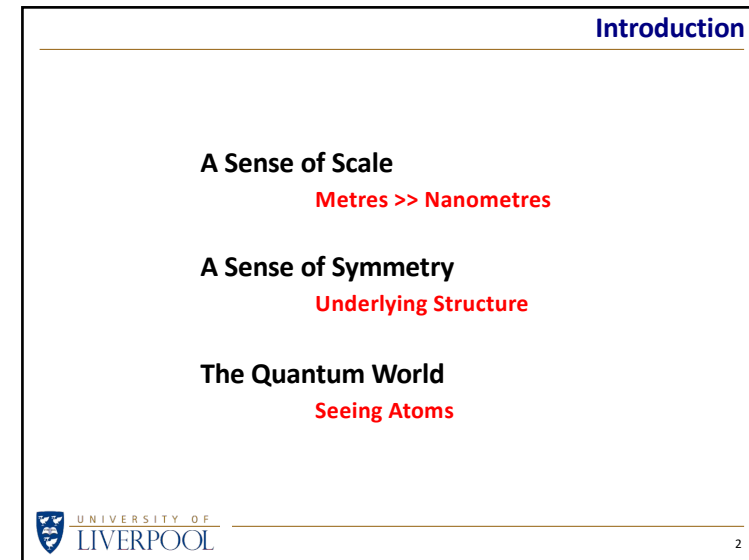
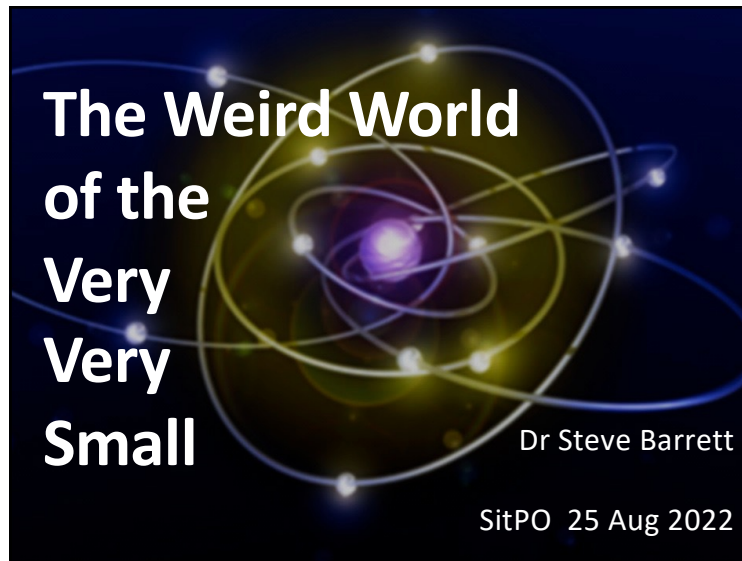
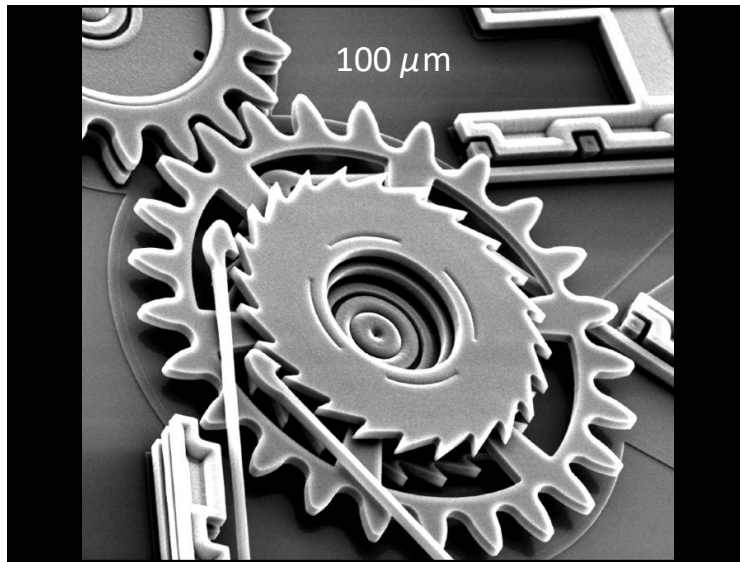


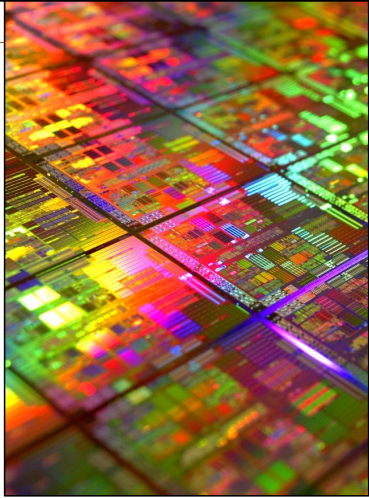
Weird World of the Very Very Small



Weird World of the Very Very Small



A Sense of Scale



Microprocessor chip area $\sim \text{mm}^2$...

100 million transistors ...

so the sizes of the components are $\sim 10 \text{ nm}$

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6

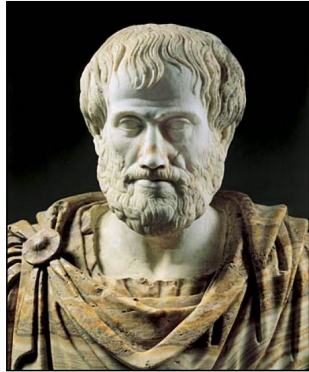
Structure Within

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

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7

Aristotle



Elements

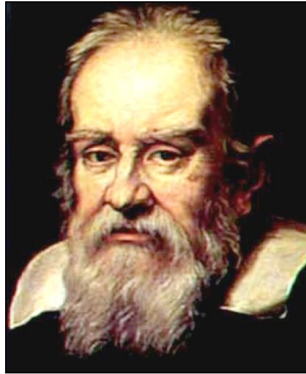
Fire
Air
Water
Earth

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8

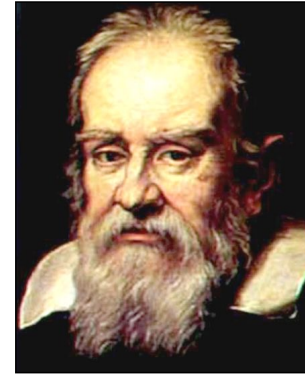
Weird World of the Very Very Small

Galileo



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

Galileo



Ask not

"What **should** happen if...?"

but

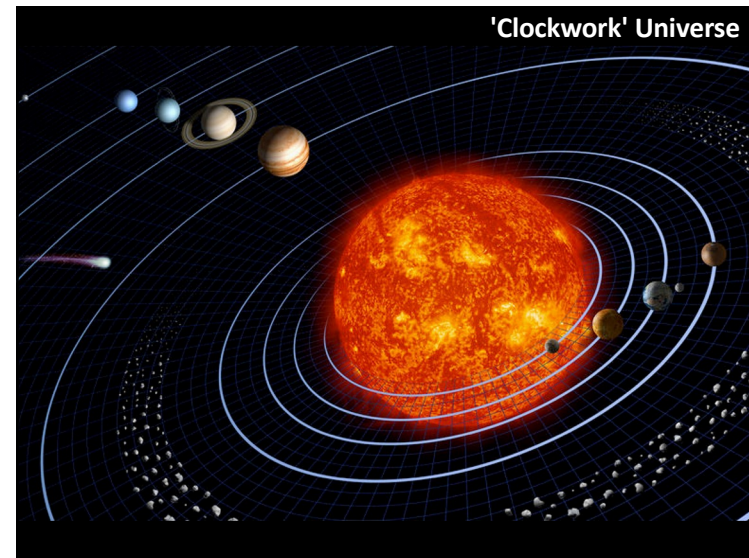
"What **actually** happens if...?"

Newton

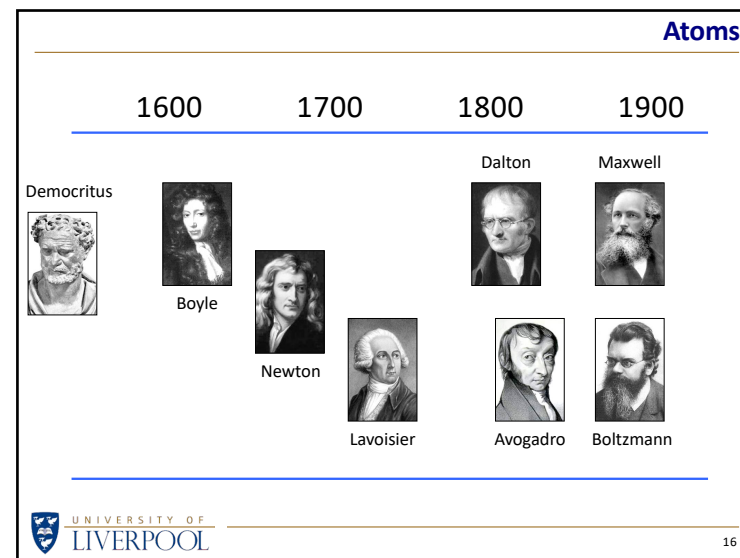
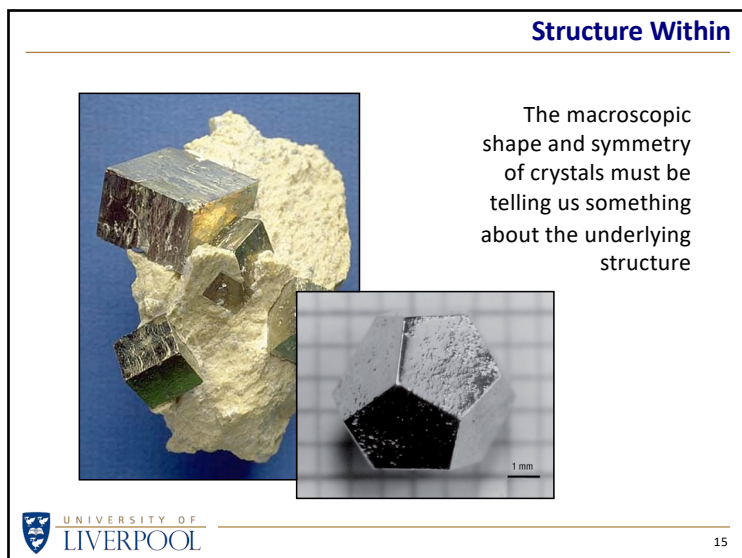
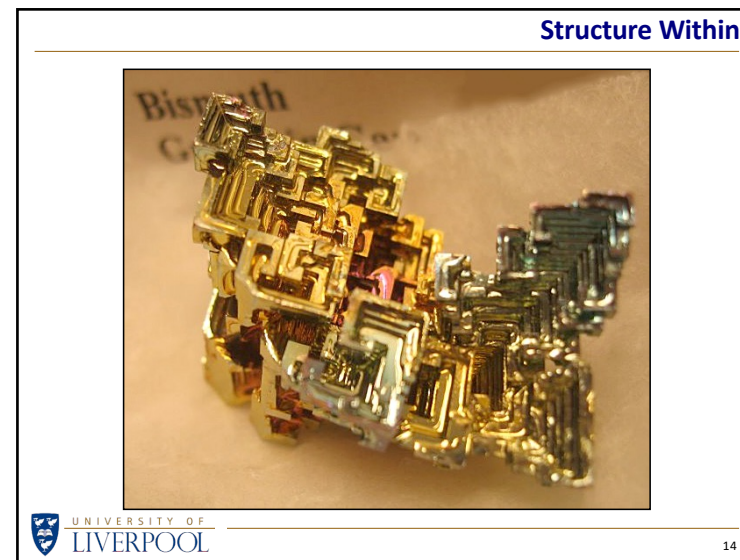
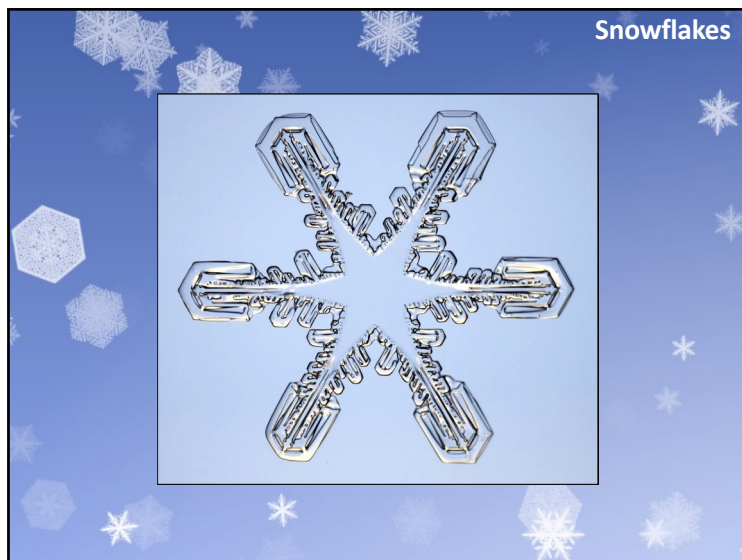


Laws of Motion
Law of Gravity
Nature of Light
"Classical Mechanics"

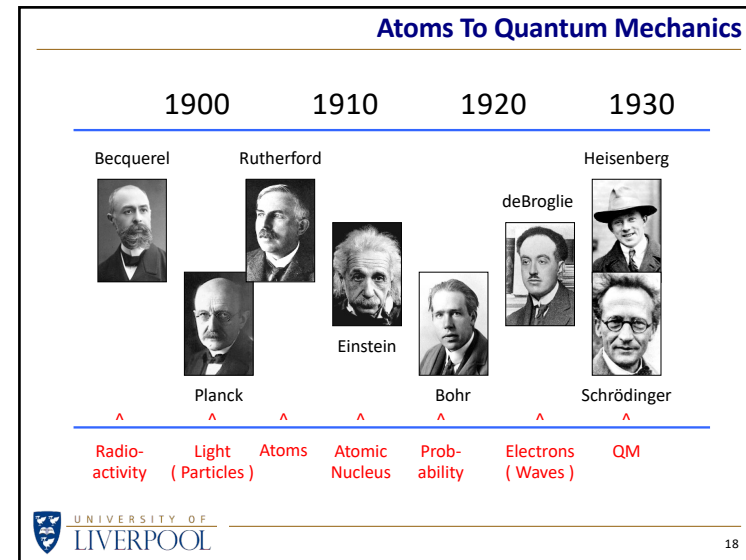
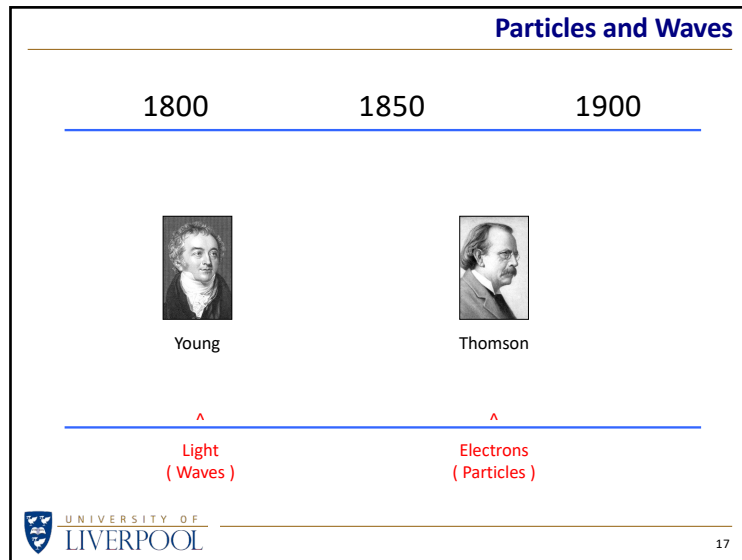
'Clockwork' Universe



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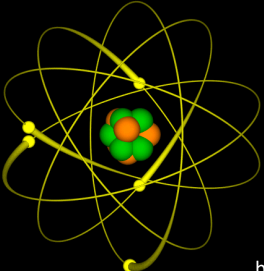


Weird World of the Very Very Small



Bohr Model

This might be how we imagine atoms with electrons buzzing around a nucleus like bees ...



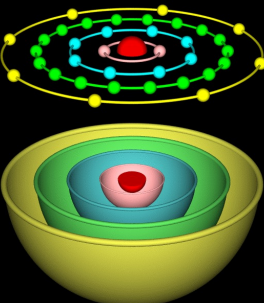
... but it doesn't show us that all the electrons have different energies

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Bohr Model

It is better to think of the electrons in different sized orbits ...



... or concentric shells surrounding the nucleus

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20

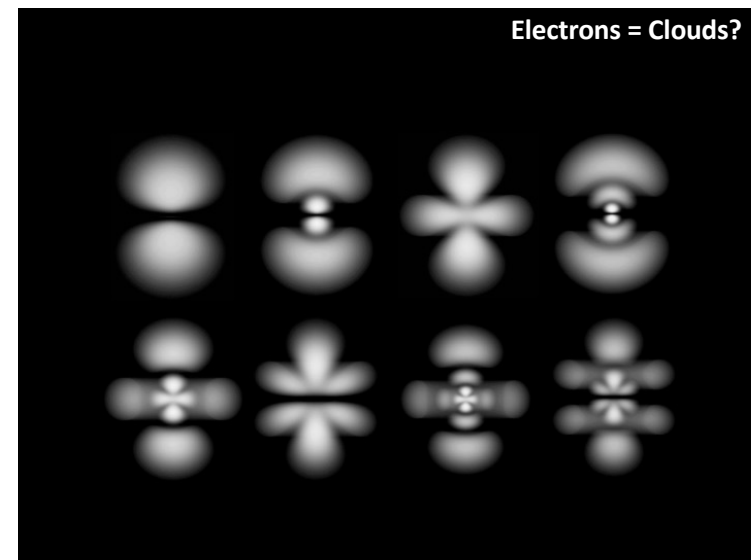
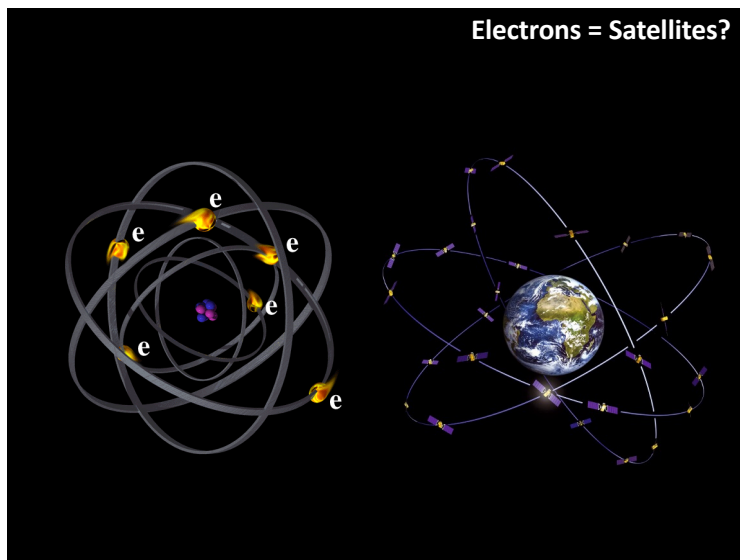
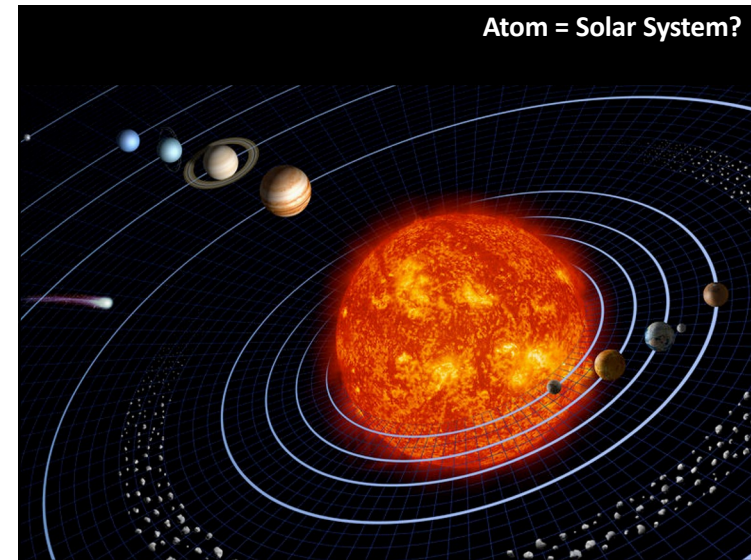
Weird World of the Very Very Small

PRODUCED BY THE FOUNDATION FOR EDUCATION, SCIENCE AND TECHNOLOGY FOR ANNUAL SET WEEK 2012

PERIODIC TABLE of the ELEMENTS

DMITRI MENDELEEV (1834 - 1907)

The Russian chemist, Dmitri Mendeleev, was the first to observe that elements were linked in a pattern. He arranged the elements in a table, and his periodic table was the first to be published. It was the first to be published in a journal, and it was the first to be published in a book. It was the first to be published in a journal, and it was the first to be published in a book. It was the first to be published in a journal, and it was the first to be published in a book.




Weird World of the Very Very Small

Dealing With Atoms

Particles
Waves
Orbits
Spin
Energy

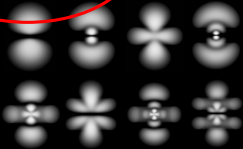
Words



Maths

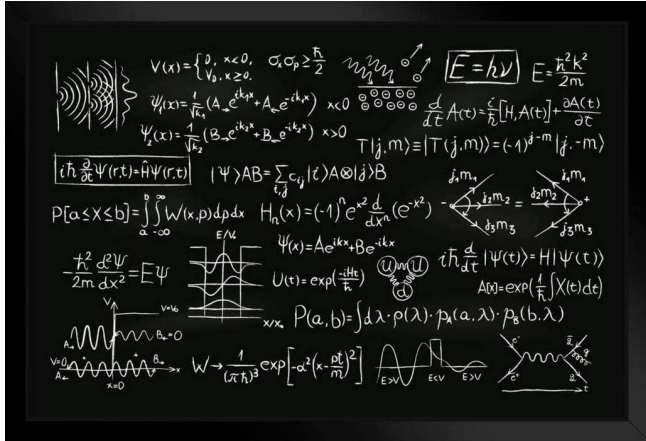
$H\psi = E\psi$

Pictures




25

Dealing With Atoms



26

Heisenberg



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

27

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 "

28

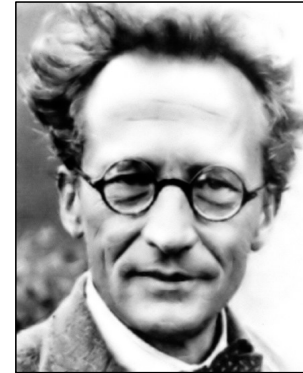
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Bohr



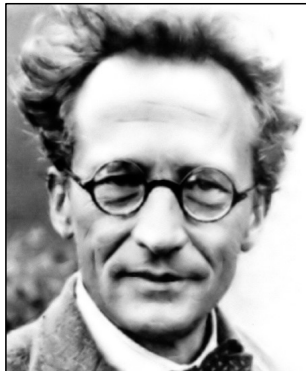
" Everything we call real is made of things that cannot be regarded as real "

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

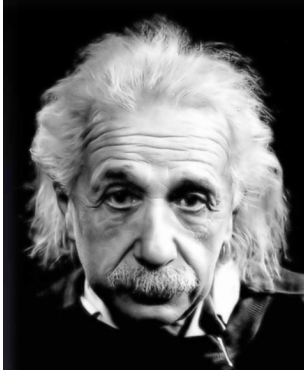
An electron 'in' an atom could be **anywhere**

Atoms can be in two states at the same time

Electron 'spin' can be simultaneously clockwise **and** anticlockwise

Weird World of the Very Very Small

Einstein

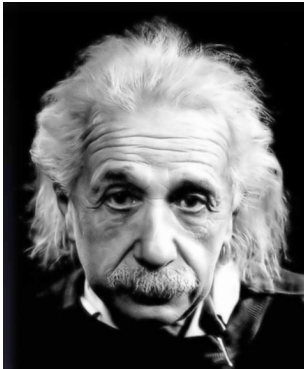


" Common sense is the collection of prejudices acquired by age eighteen "

Heads or Tails?



Einstein



" God does not play dice "

" God is subtle but he is not malicious "

Bohr



" Stop telling God what to do! "

Weird World of the Very Very Small

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

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

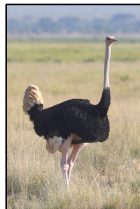
So what?

If Order Matters



Top pair : carnivores

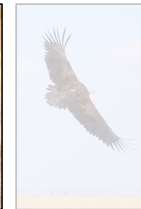
Bottom pair : veggies



Left pair : four legs

Right pair : wings

If Order Matters



Pick 2 out of the 4

For instance, pick the
veggie animals

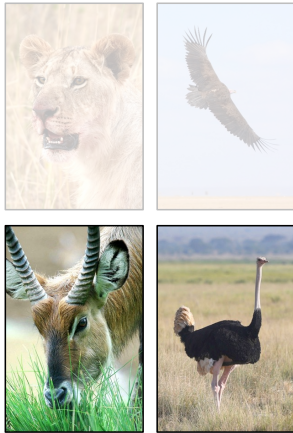
From these, pick again

For instance, pick the
4-legged animals

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

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If Order Matters



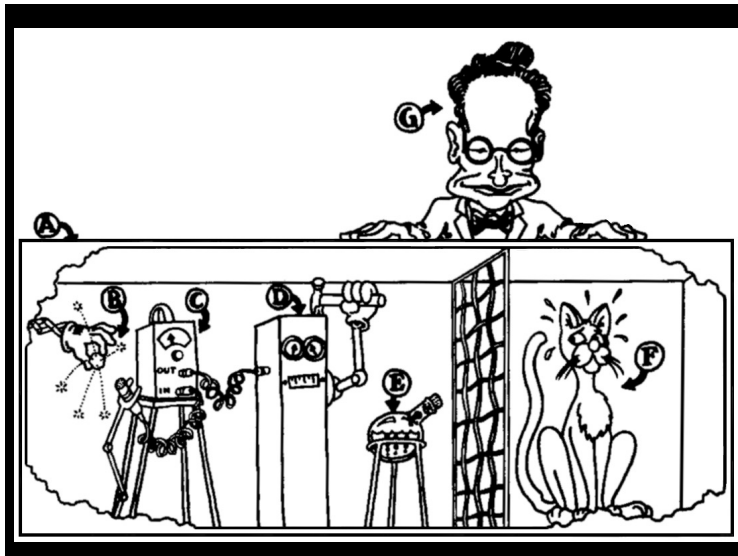
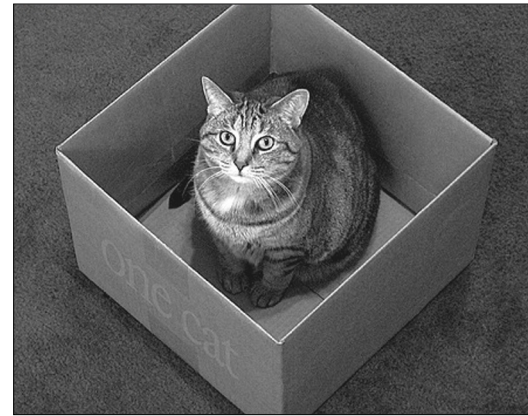
If we had picked in a different order ...

First pick the **4-legged** animals

Then pick the **veggie** animals

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

Schrödinger's Cat



Schrödinger's Cat

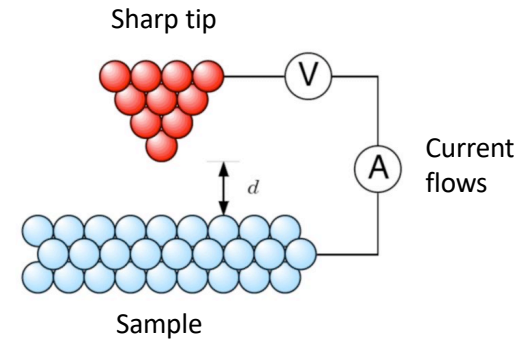


Weird World of the Very Very Small

How Do We Know QM Is Right?

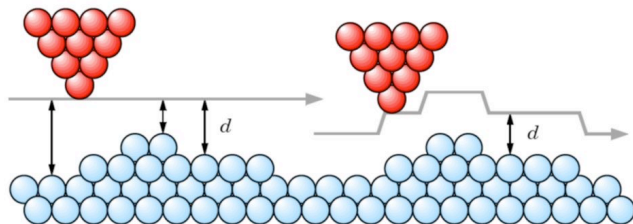
- So far, nothing has proved it wrong
- Quantum Mechanics predicts results that are impossible by 'Classical Mechanics'
- Using QM theory, we can build a microscope that can 'see' atoms

Scanning Tunnelling Microscope



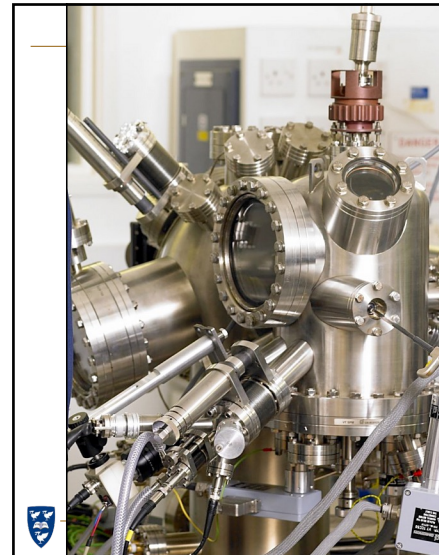
STM

Move the tip across the sample ...



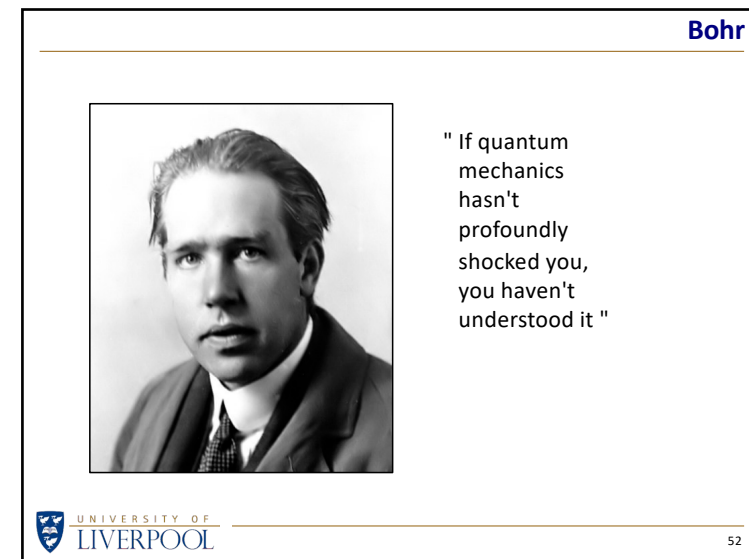
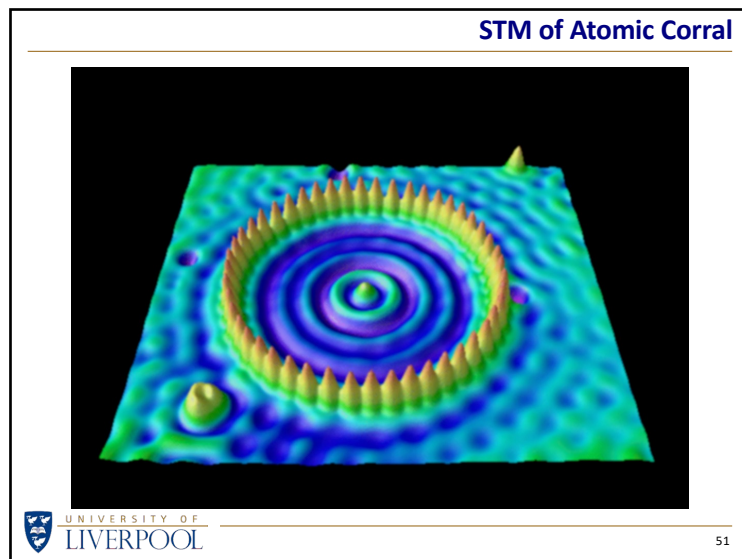
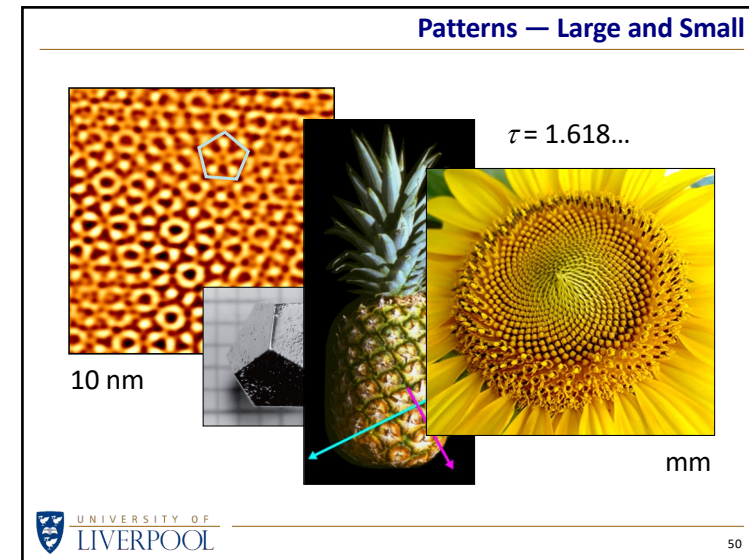
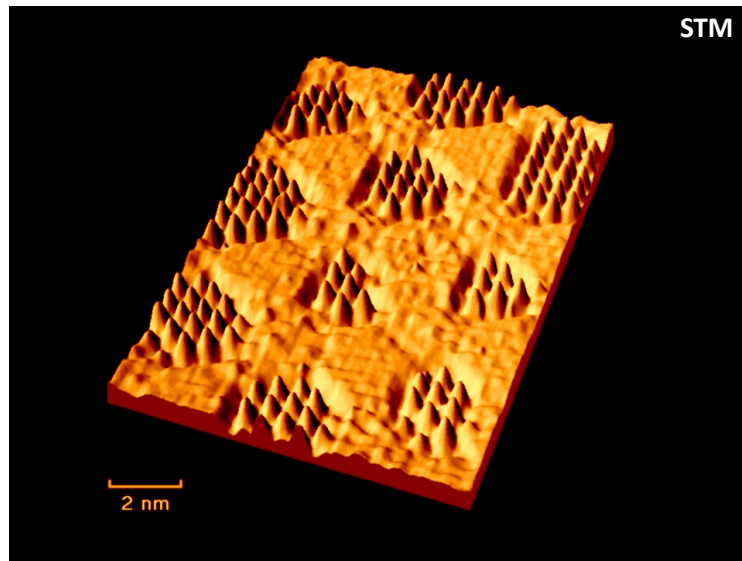
... measuring the current at each point

Surface Science



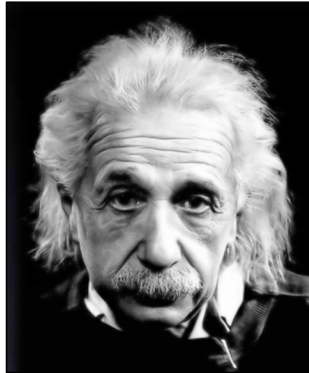
The STM is sealed inside an ultra-high vacuum vessel (10^{-13} atms) to keep it and the sample surface clean.

Weird World of the Very Very Small



Weird World of the Very Very Small

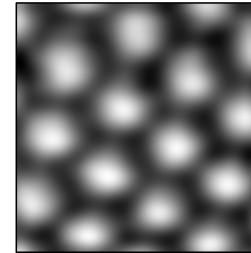
Einstein



" The most
incomprehensible
thing about the
world ...

... is that it is
comprehensible "

A World of Atoms



850 pm

On this scale, a grain of
sand would be about
the size of the Moon.

" To see a world in
a grain of sand ... "

William Blake

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
SitPO

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

25 Aug 2022