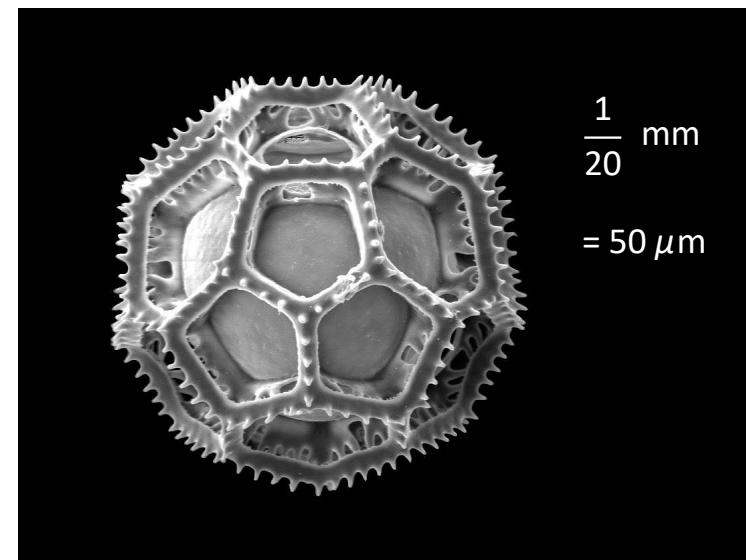
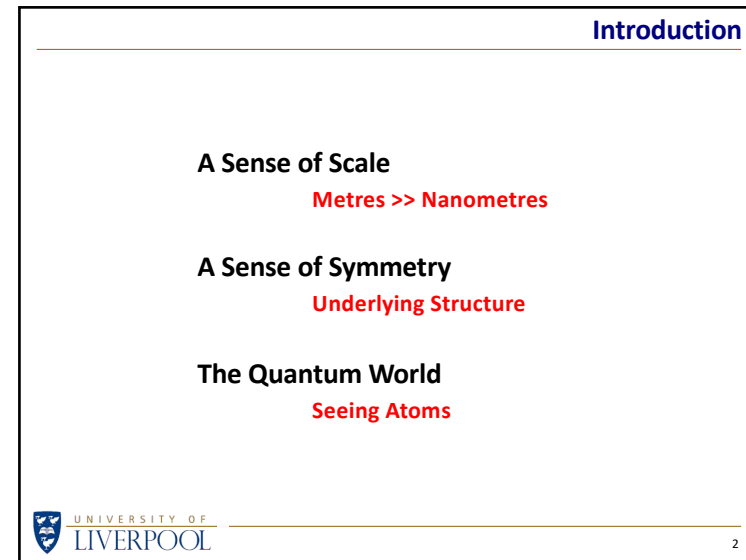
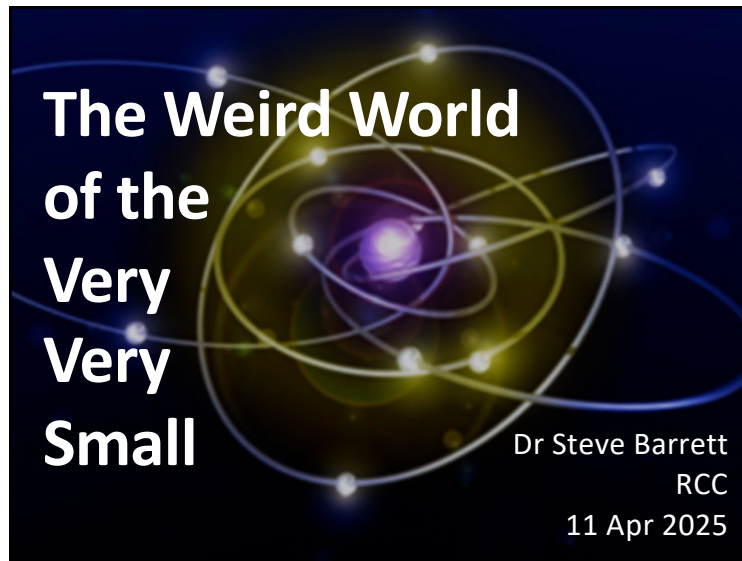
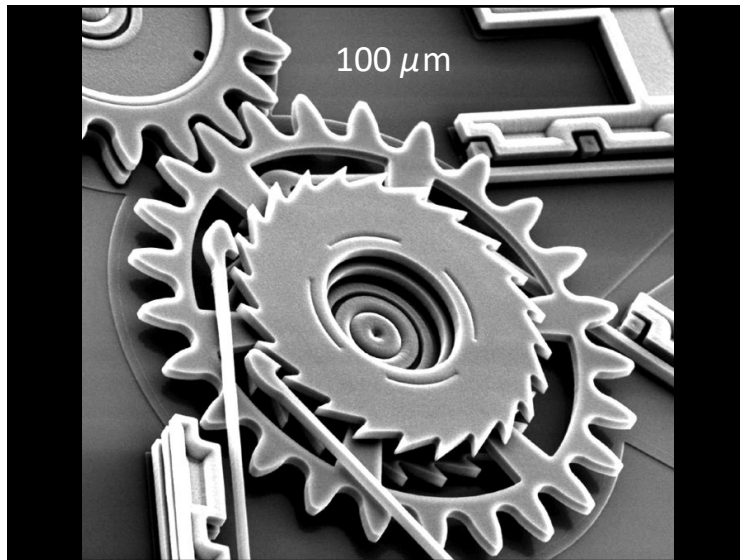


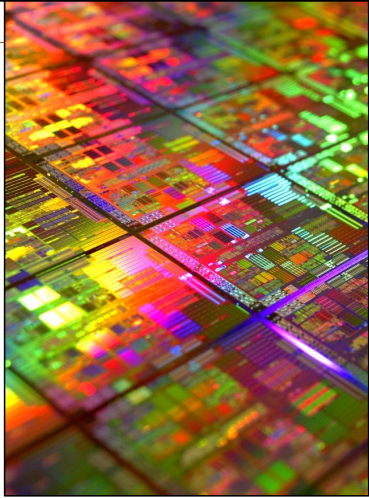
Weird World of the Very Very Small



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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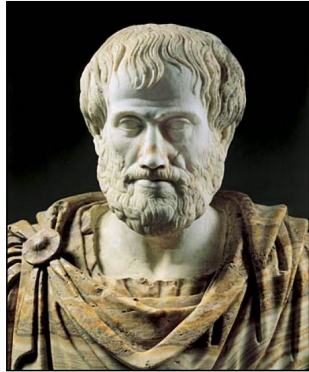
Structure Within

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

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Aristotle



Elements

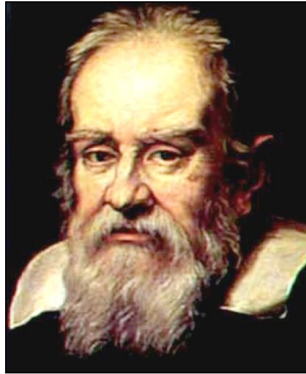
Fire
Air
Water
Earth

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8

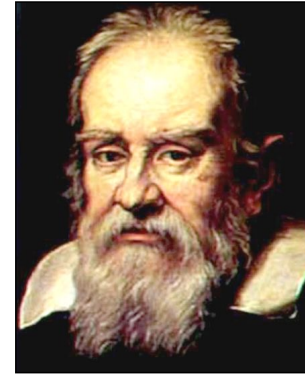
Weird World of the Very Very Small

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

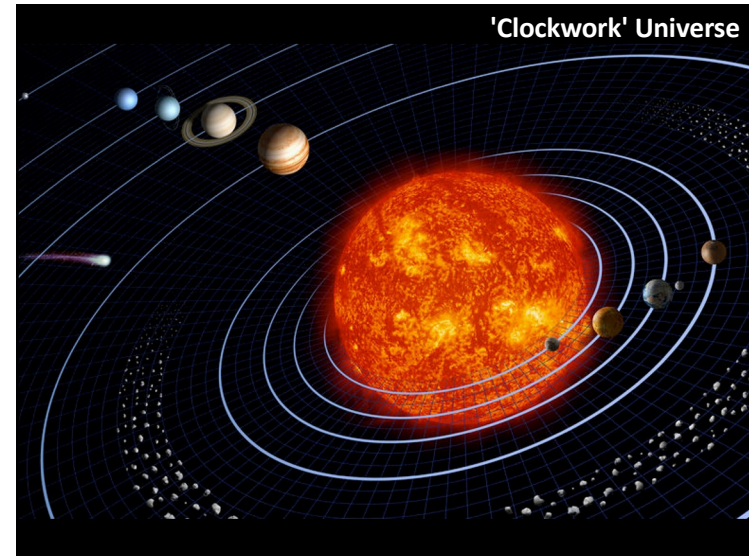
"What **actually** happens if...?"

Newton

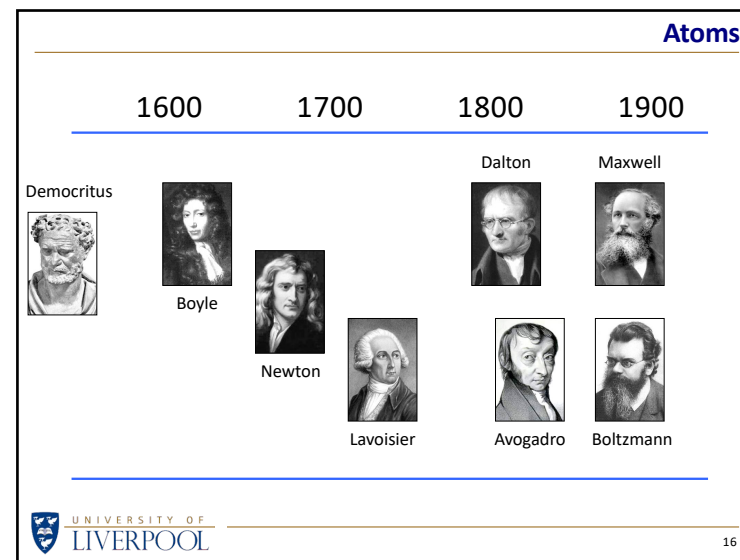
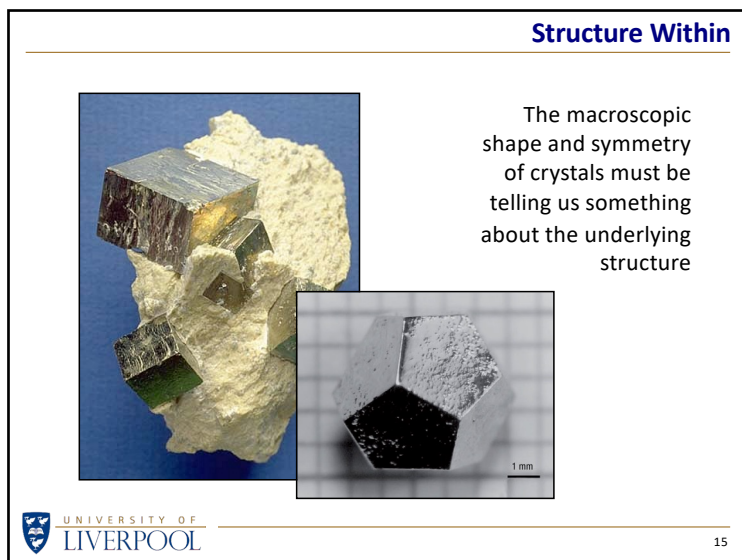
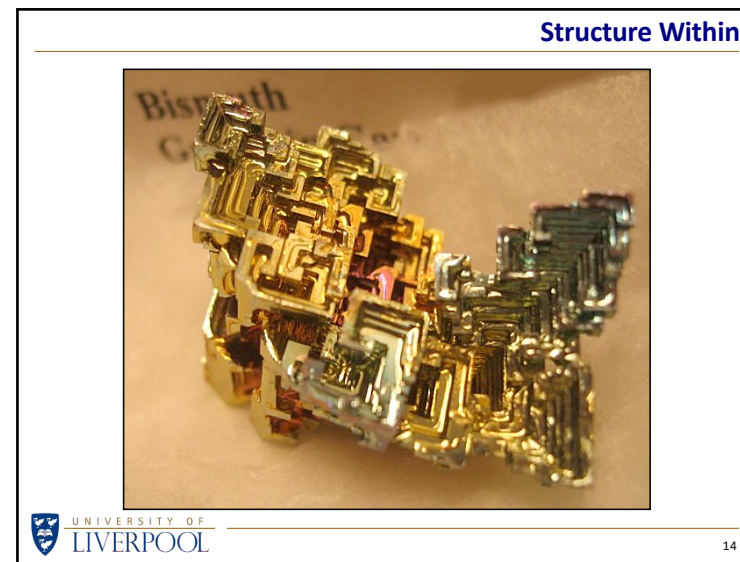
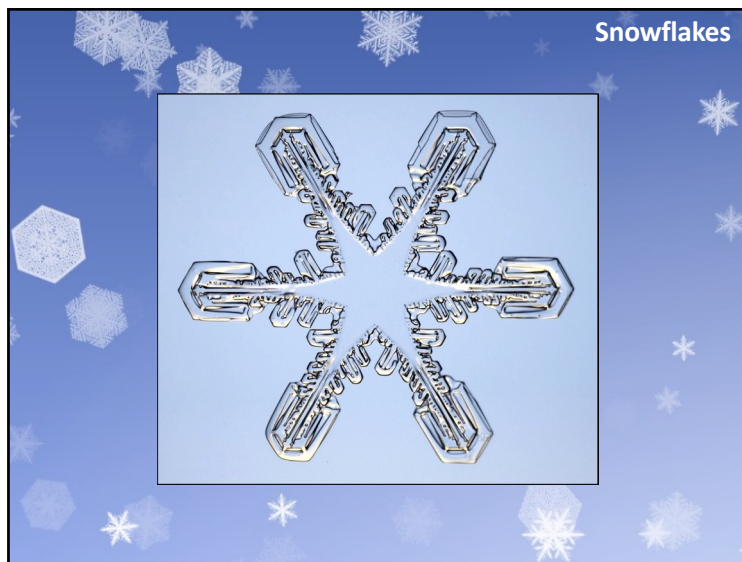


Laws of Motion
Law of Gravity
Nature of Light
"Classical Mechanics"

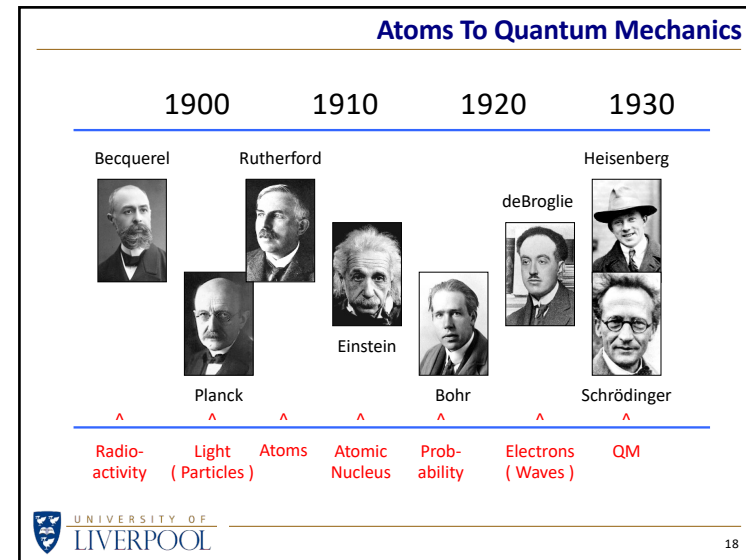
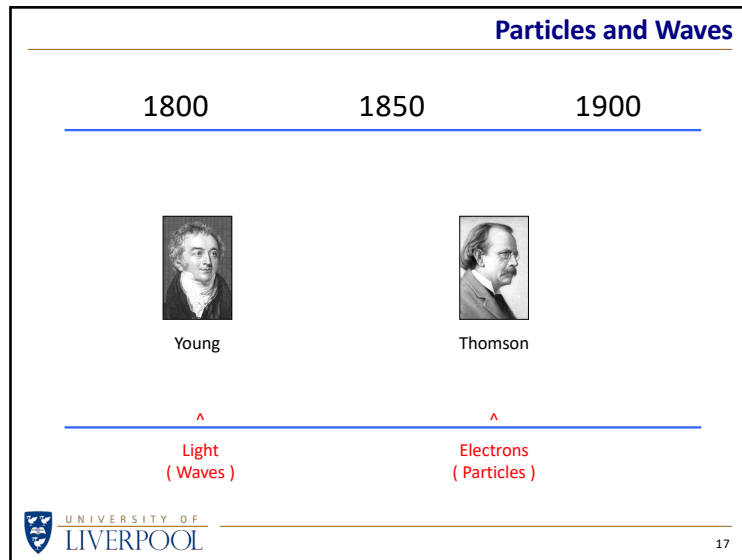
'Clockwork' Universe



Weird World of the Very Very Small

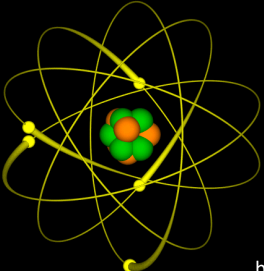


Weird World of the Very Very Small



Bohr Model

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



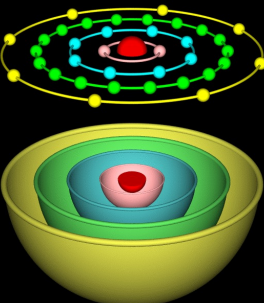
... but it doesn't show us that all the electrons have different energies

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Bohr Model

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



... or concentric shells surrounding the nucleus

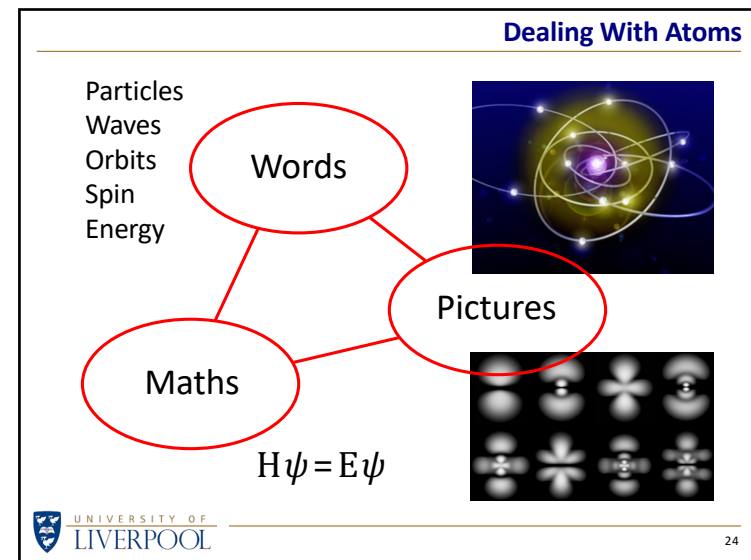
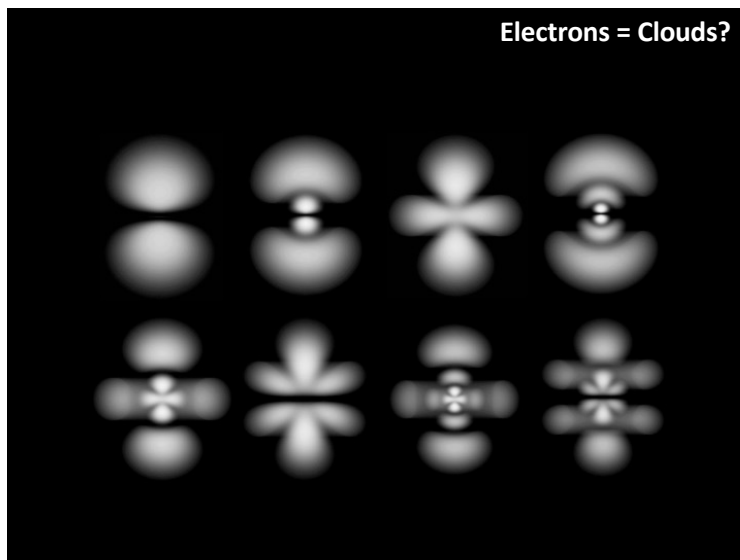
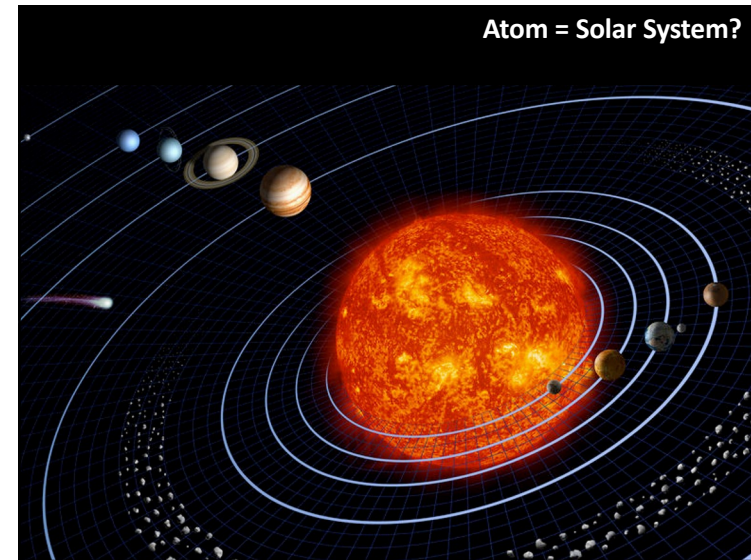
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Weird World of the Very Very Small

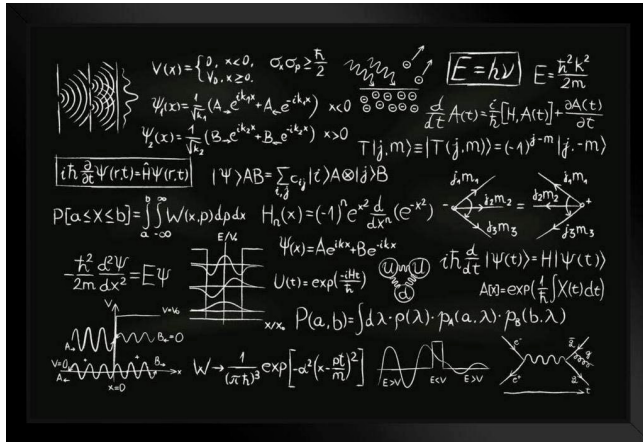
PERIODIC TABLE of the ELEMENTS

DMITRI MENDELEEV (1834 - 1907)



Weird World of the Very Very Small

Dealing With Atoms



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 "

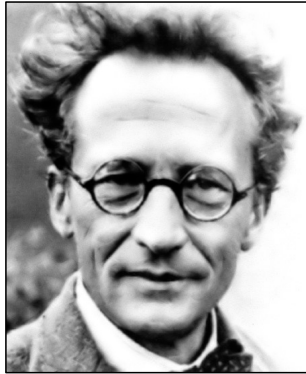
Bohr



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

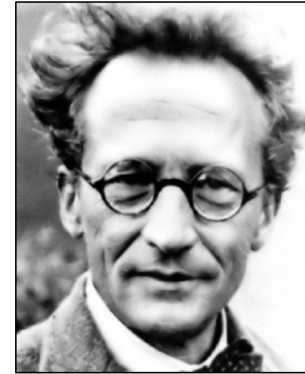
Weird World of the Very Very Small

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, ...

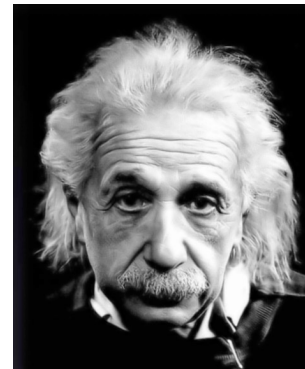
Atoms do not have a finite size

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



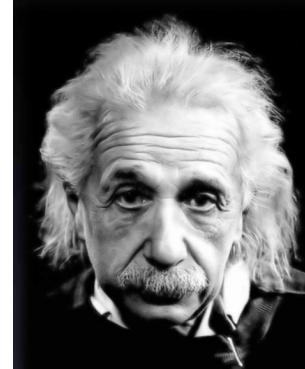
" Common sense is the collection of prejudices acquired by age eighteen "

Weird World of the Very Very Small

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

Weird World of the Very Very Small

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



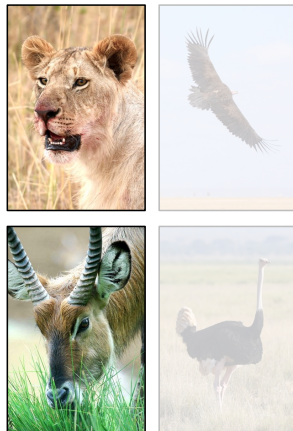
Top pair : carnivores

Bottom pair : veggies

Left pair : four legs

Right pair : wings

If Order Matters



Pick 2 out of the 4

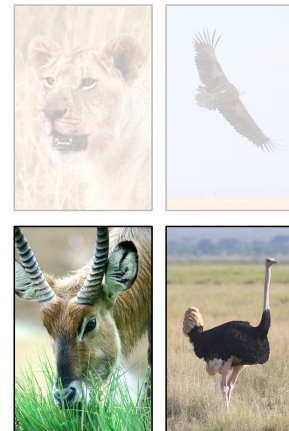
For instance, pick the **veggie** animals

From these, pick again

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

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

If Order Matters



If we had picked in a different order ...

First pick the **4-legged** animals

Then pick the **veggie** animals

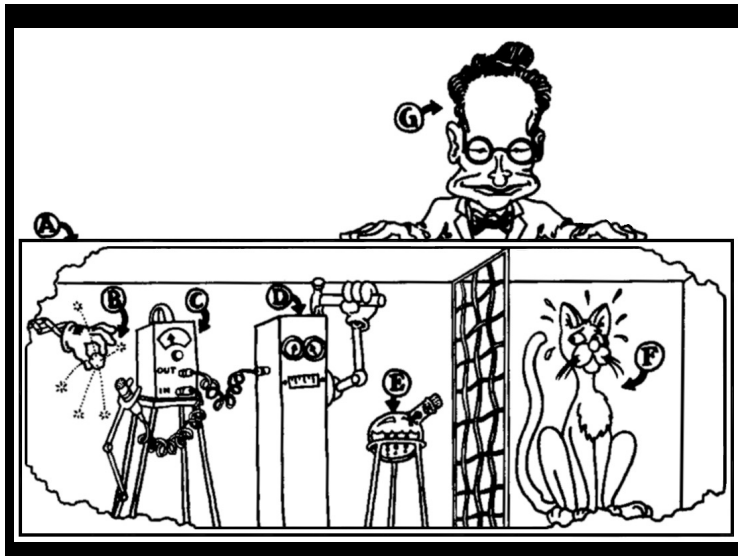
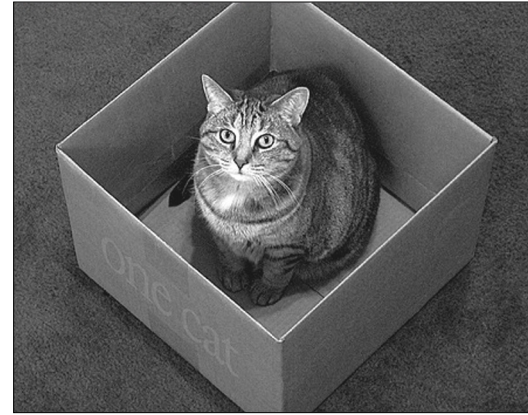
You're left with waterbuck **and** ostrich!

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Schrödinger's Cat



Schrödinger's Cat



Schrödinger's Cat

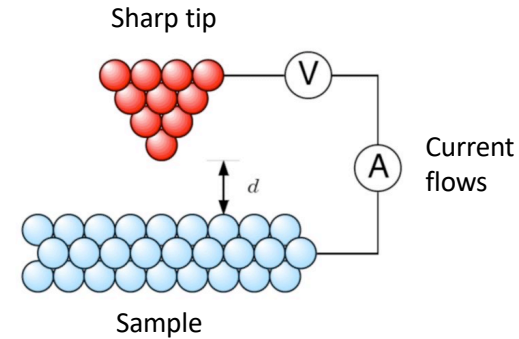


Weird World of the Very Very Small

How Do We Know QM Is Right?

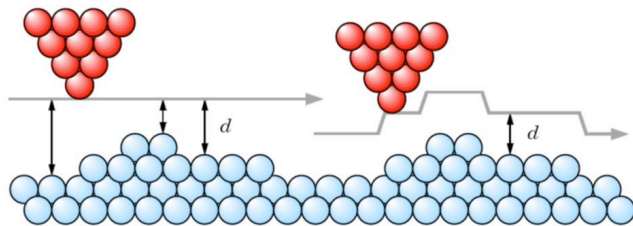
- So far, nothing has proved it wrong
- Quantum Mechanics predicts results that are impossible by 'Classical Mechanics'
- Using QM theory, we can build a microscope that can 'see' atoms

Scanning Tunnelling Microscope



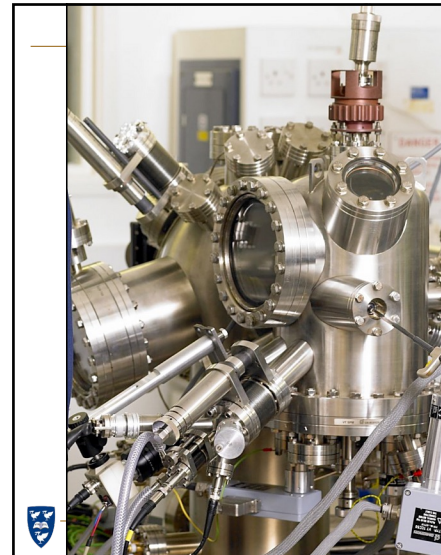
STM

Move the tip across the sample ...



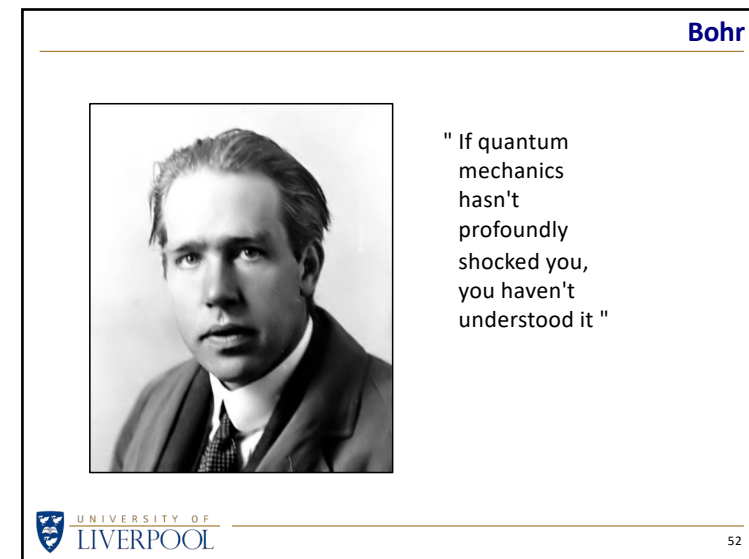
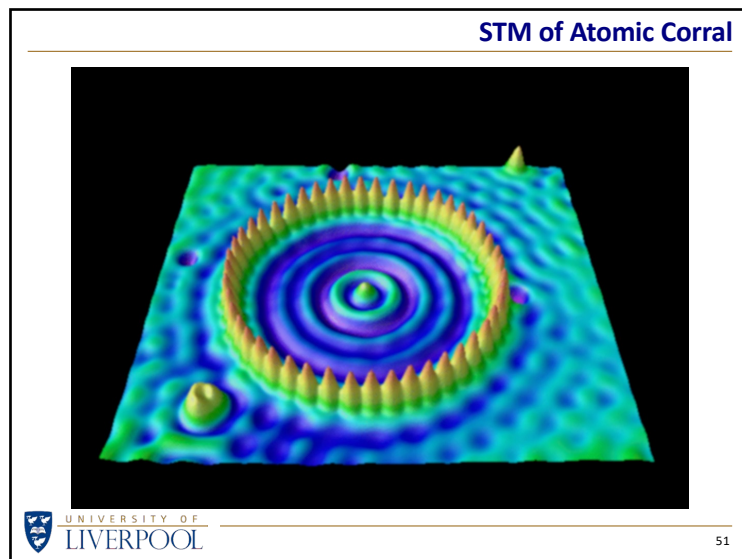
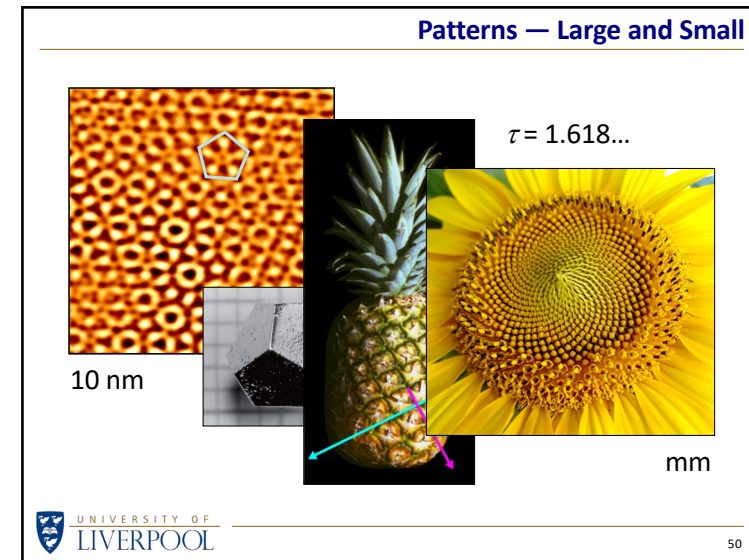
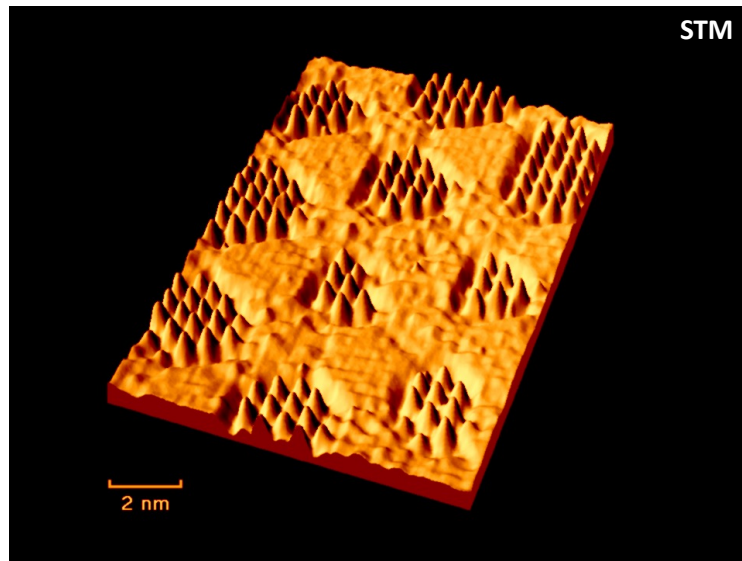
... measuring the current at each point

Surface Science



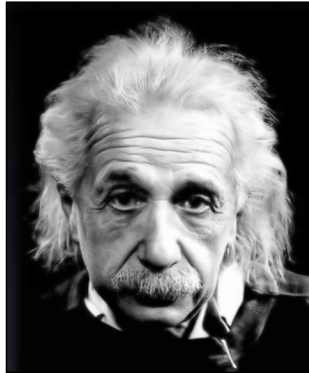
The STM is sealed inside an ultra-high vacuum vessel (10^{-13} atms) to keep it and the sample surface clean.

Weird World of the Very Very Small



Weird World of the Very Very Small

Einstein



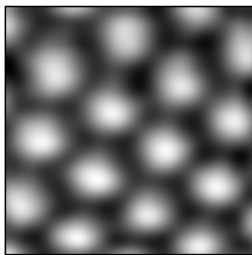
" The most
incomprehensible
thing about the
world ...

... is that it is
comprehensible "

Hmmm ...



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

The Weird World
of the
Very
Very
Small

Dr Steve Barrett
RCC

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

11 Apr 2025