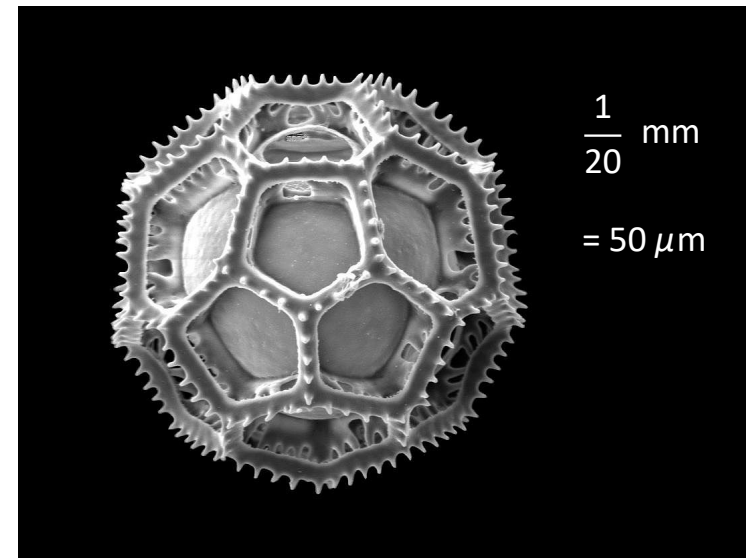
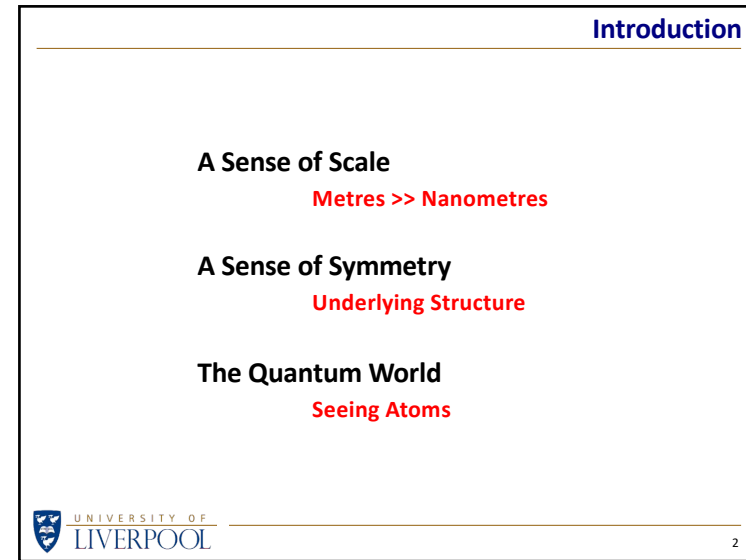
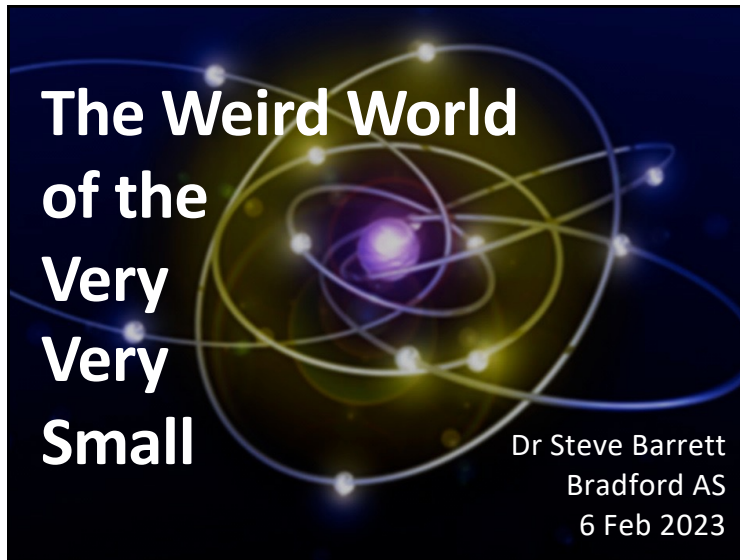
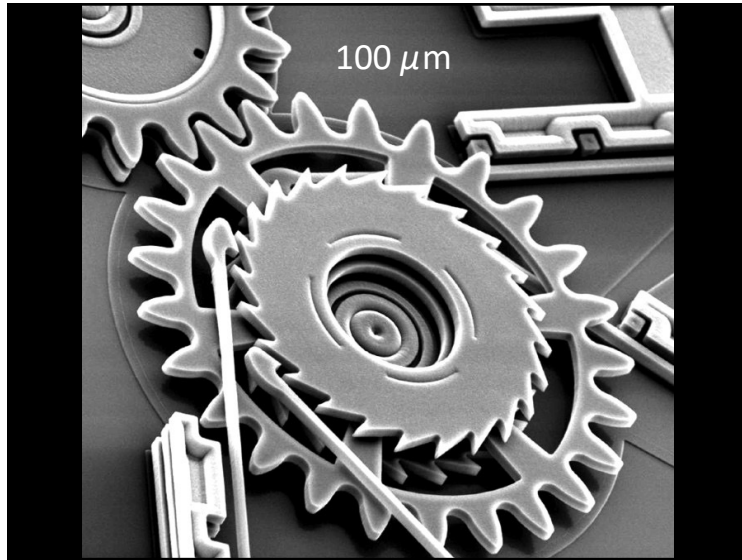


Weird World of the Very Very Small



Weird World of the Very Very Small

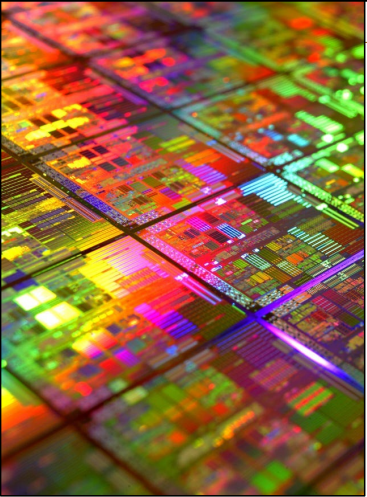


A Sense of Scale

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?

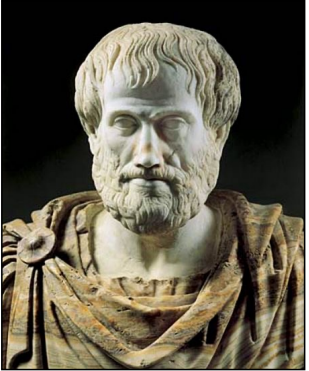


7

Aristotle

Elements

Fire
Air
Water
Earth

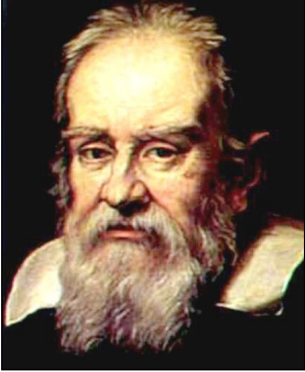


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Weird World of the Very Very Small

Galileo

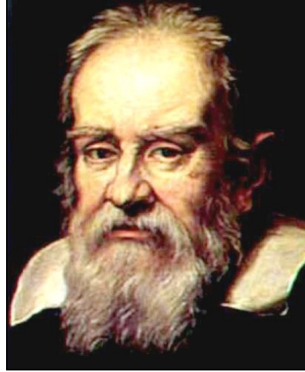


The nature of the world around us should be determined by **quantitative** experiments, not by **qualitative** intellectual arguments

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Galileo

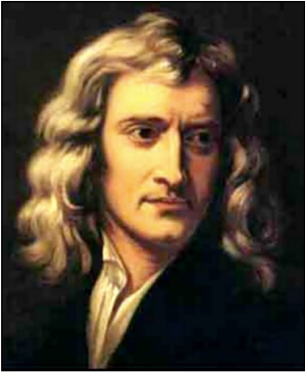


Ask not
"What **should** happen if...?"
but
"What **actually** happens if...?"

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10

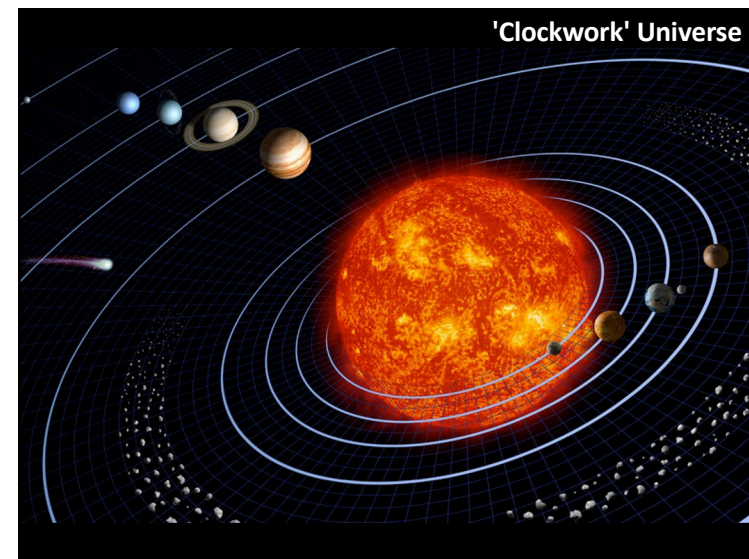
Newton



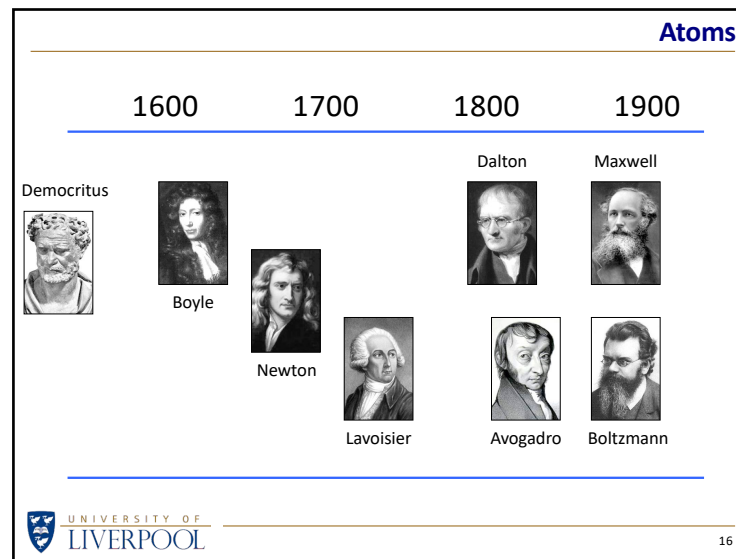
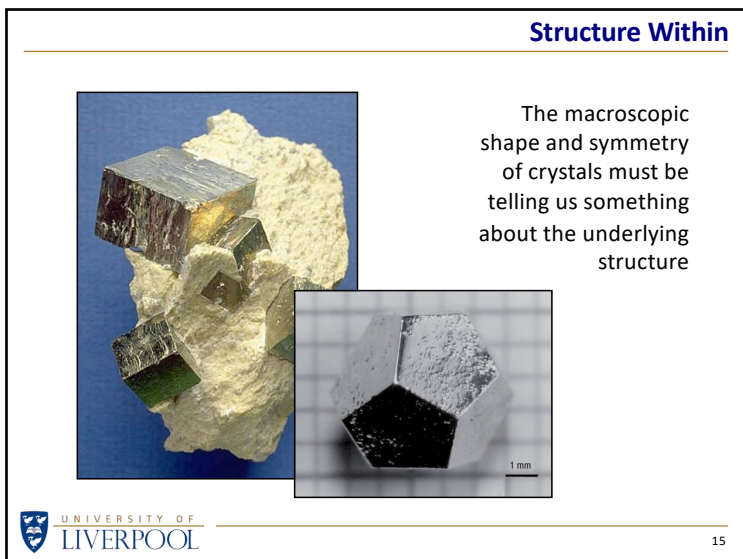
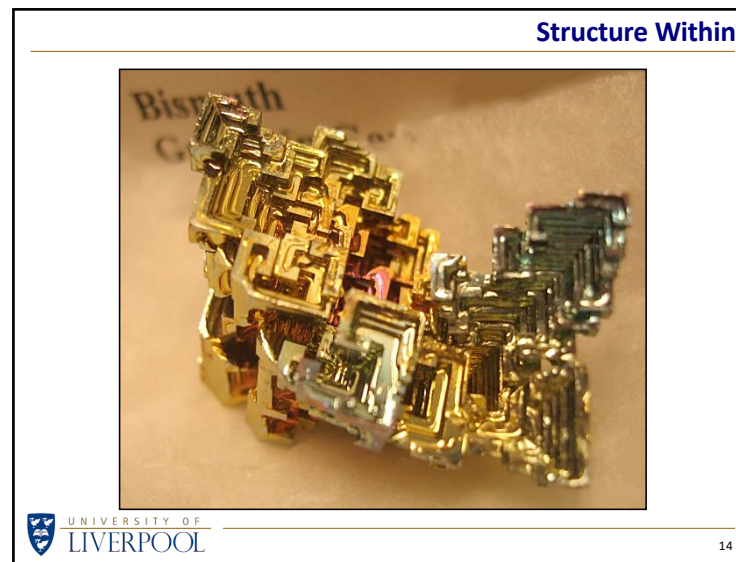
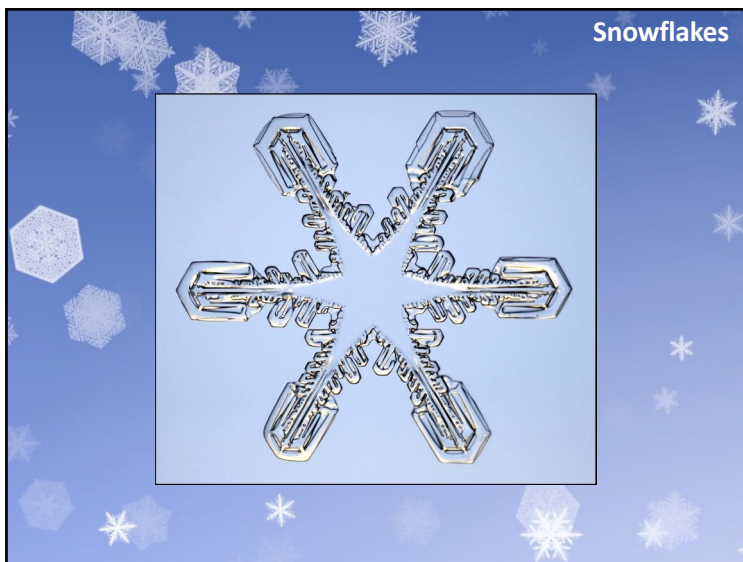
Laws of Motion
Law of Gravity
Nature of Light
"Classical Mechanics"

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11




Weird World of the Very Very Small




Weird World of the Very Very Small

Particles and Waves

1800 1850 1900



Young



Thomson

^

Light
(Waves)

^


Electrons
(Particles)

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Atoms To Quantum Mechanics

1900 1910 1920 1930


Becquerel




Rutherford

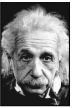


Heisenberg






Planck





Einstein



Bohr

deBroglie





Schrödinger

^

Radio-activity

^

Light
(Particles)

^

Atoms

^

Atomic
Nucleus

^

Prob-ability

^

Electrons
(Waves)

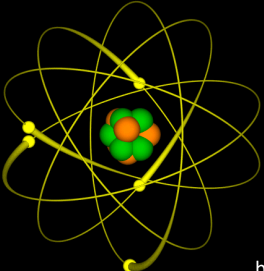
^

QM

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Bohr Model

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

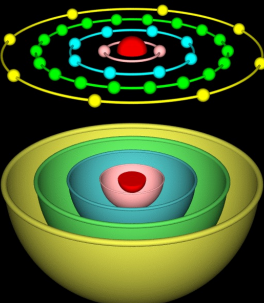


... but it doesn't show us that all the electrons have different energies

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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

PRODUCED BY THE FOUNDATION FOR EDUCATION, SCIENCE AND TECHNOLOGY FOR NATIONAL DAY WEEK 2013

TRULY INSPIRED BY SHUTTLEWORTH

DMITRI MENDELEEV (1834 - 1907)

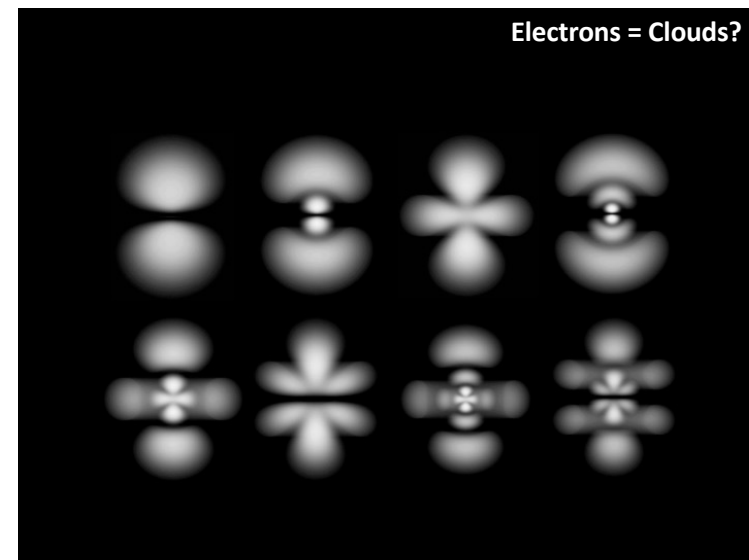
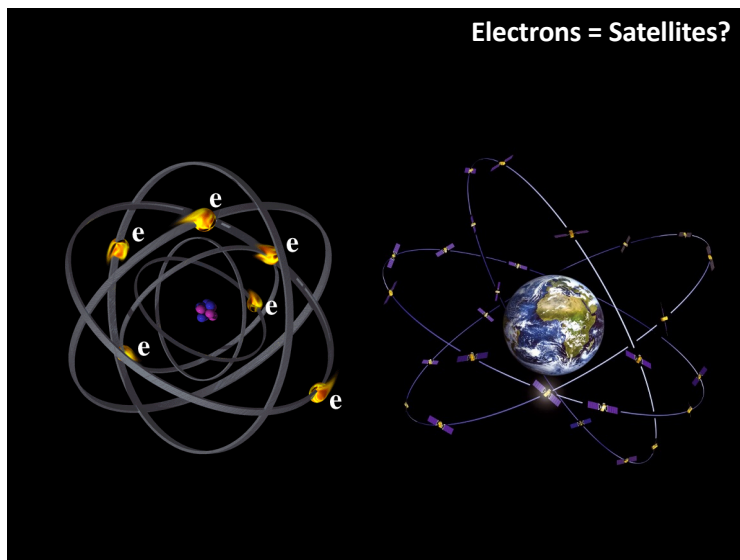
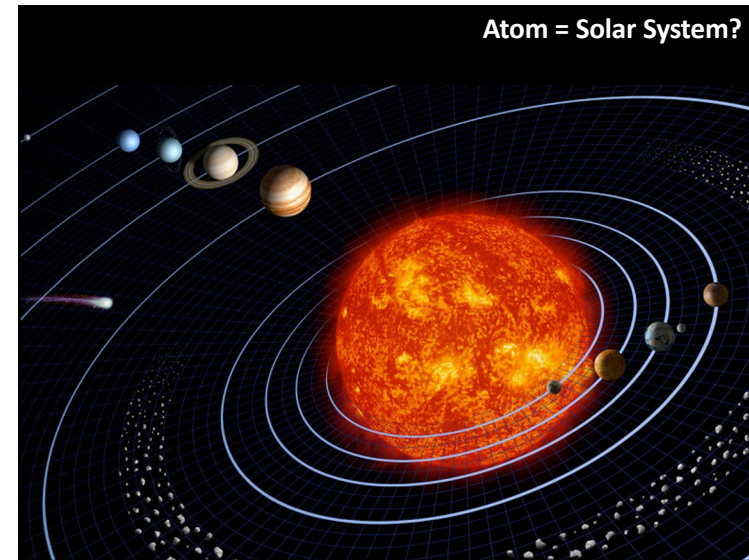
The Russian chemist, Dmitri Mendeleev, was the first to discover that elements can be listed in order of atomic mass. This allowed him to predict the properties of the elements that were missing from his periodic table of elements. Now regarded as the father of modern chemistry.

The ordering of elements in Mendeleev's periodic table was the beginning of the modern periodic law. In 1913, the year he published his periodic table, scientists began to understand the atomic structure of matter. Mendeleev's periodic table was the first to show the periodicity of the elements and the prediction was found to be accurate. These elements formed and their chemical properties were predicted by Mendeleev.

This periodic table was prepared in a variety of 17 colors. You will be able to identify the elements in the periodic table and predict the properties of the elements.

● Solid state
● Liquid state
● Gas state and liquid
● Radioactive

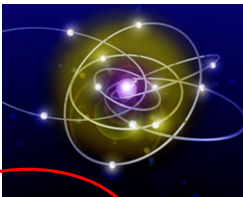
Ac Th Pa U Np Pu Am Cm Bk Cf Es Fm Md No Lr



Weird World of the Very Very Small

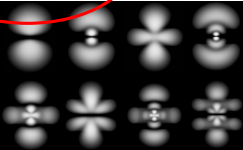
Dealing With Atoms

Particles
Waves
Orbits
Spin
Energy




Words

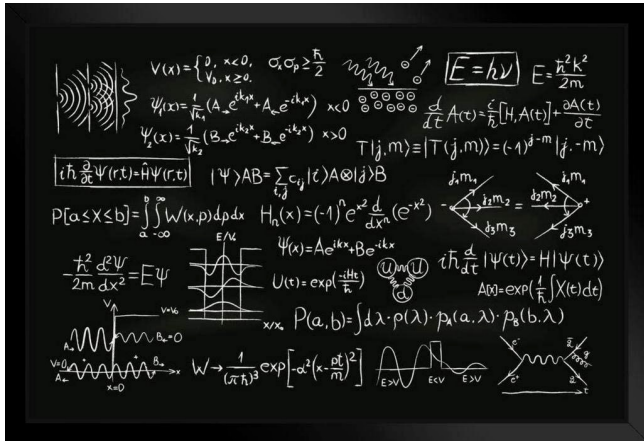
Maths




$H\psi = E\psi$



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

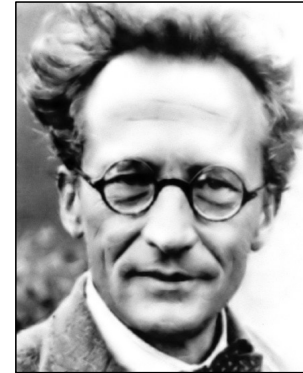
Weird World of the Very Very Small

Bohr



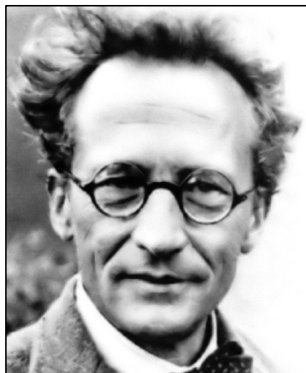
" Everything we call real is made of things that cannot be regarded as real "

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

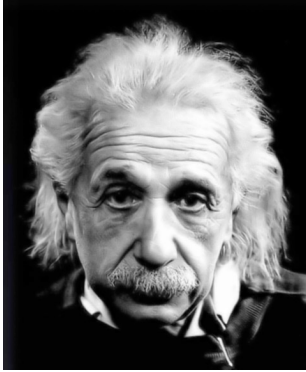
Atoms (indeed, all particles) are unpredictable
We can know only the **probability** of an atom having a particular position, speed, energy, ...

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

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Einstein

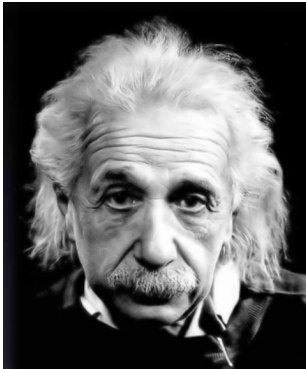


" Common sense is the collection of prejudices acquired by age eighteen "

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

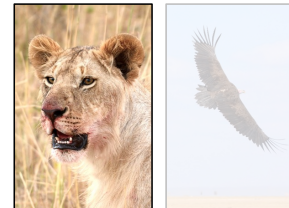


Top pair : carnivores
Bottom pair : veggies



Left pair : four legs
Right pair : wings

If Order Matters



Pick 2 out of the 4

For instance, pick the
veggie animals

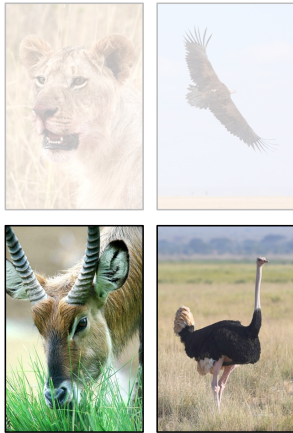
From these, pick again

For instance, pick the
4-legged animals

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

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If Order Matters



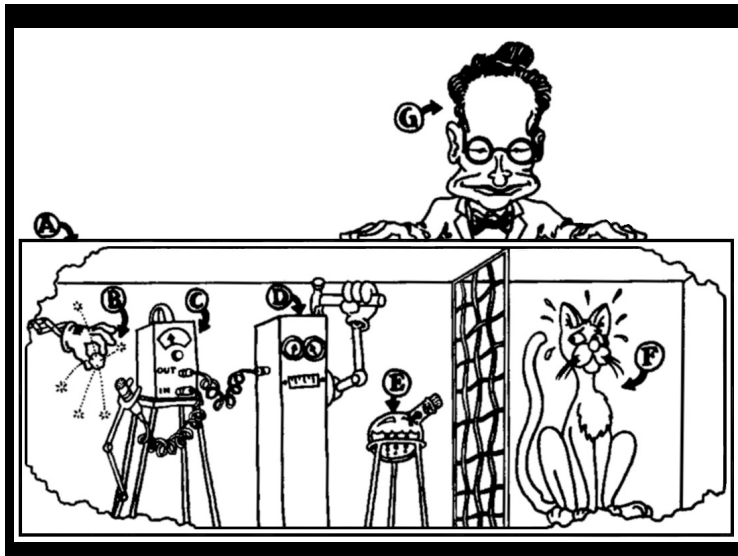
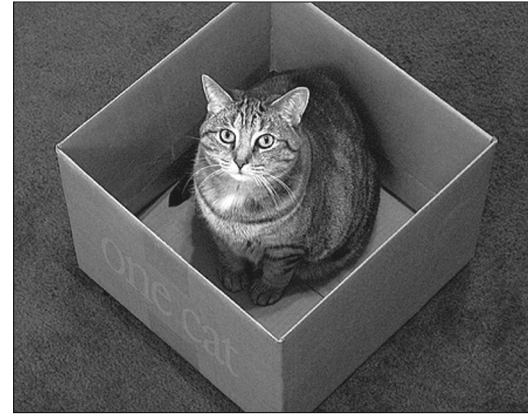
If we had picked in a different order ...

First pick the **4-legged** animals

Then pick the **veggie** animals

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

Schrödinger's Cat



Schrödinger's Cat

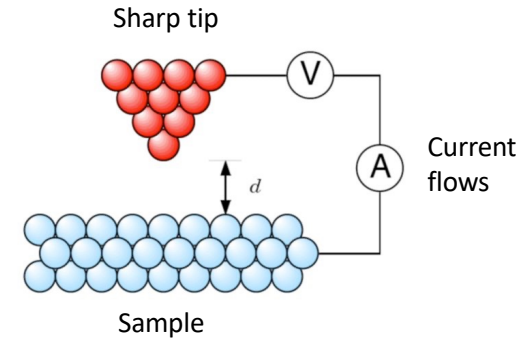


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How Do We Know QM Is Right?

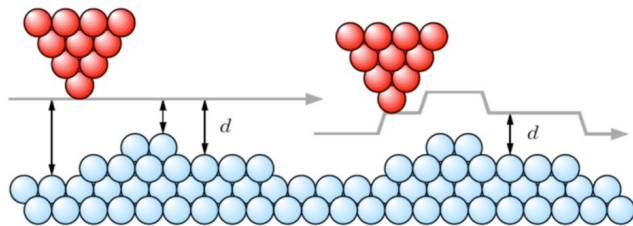
- So far, nothing has proved it wrong
- Quantum Mechanics predicts results that are impossible by 'Classical Mechanics'
- Using QM theory, we can build a microscope that can 'see' atoms

Scanning Tunnelling Microscope



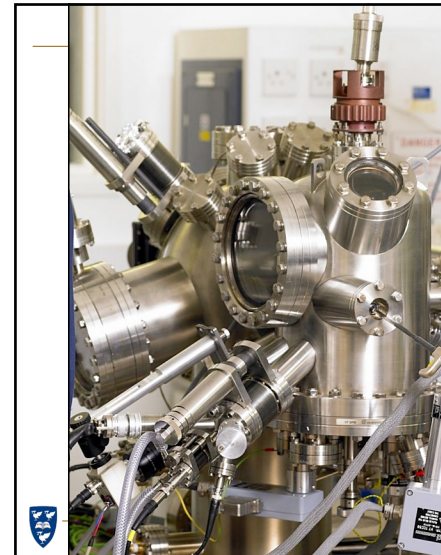
STM

Move the tip across the sample ...



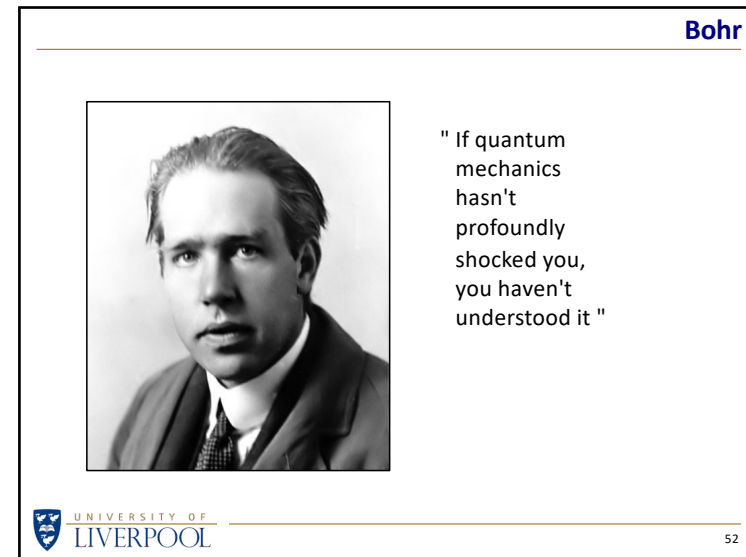
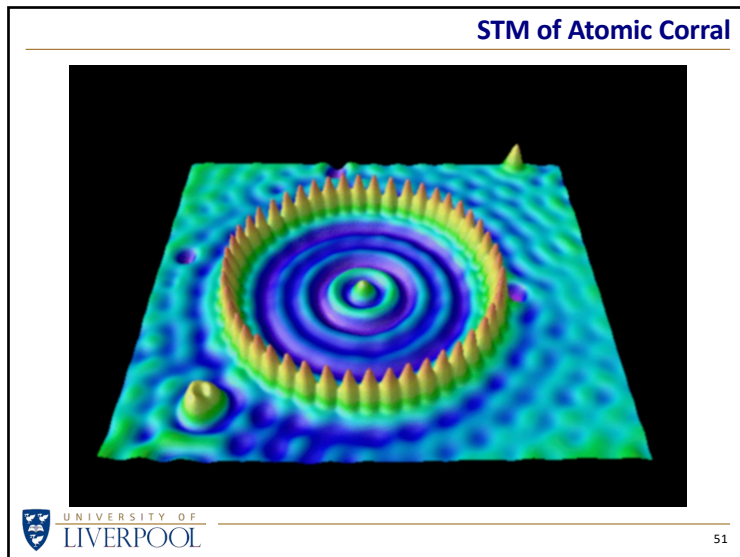
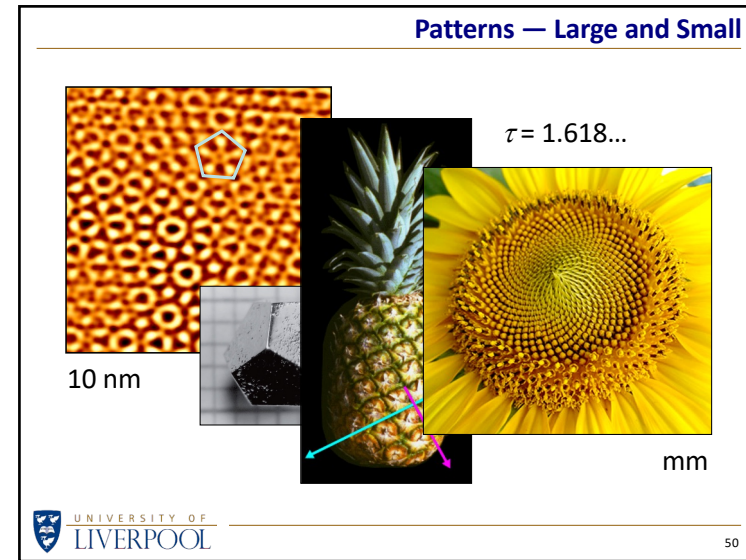
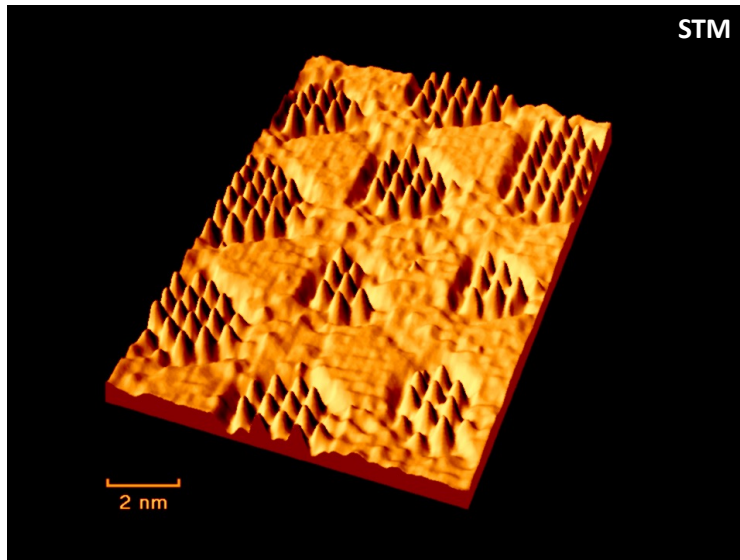
... measuring the current at each point

Surface Science



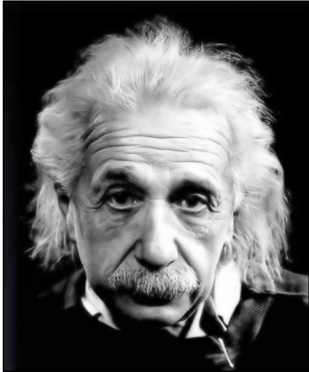
The STM is sealed inside an ultra-high vacuum vessel (10^{-13} atms) to keep it and the sample surface clean.

Weird World of the Very Very Small



Weird World of the Very Very Small

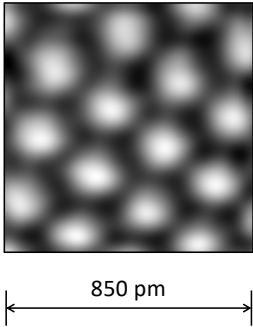
Einstein



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

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A World of Atoms



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

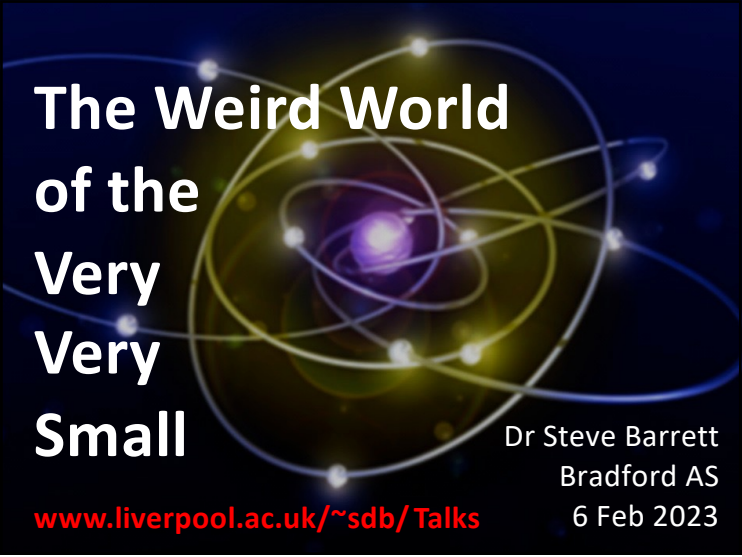
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William Blake

*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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**The Weird World
of the
Very
Very
Small**



Dr Steve Barrett
Bradford AS
6 Feb 2023

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