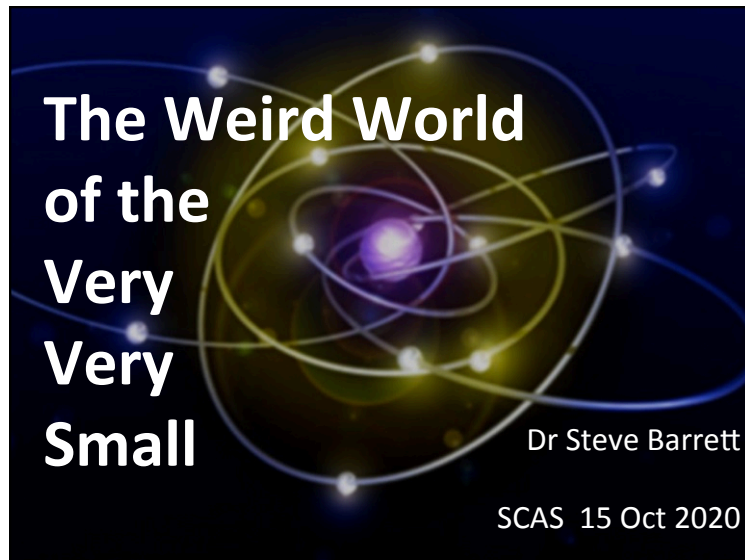
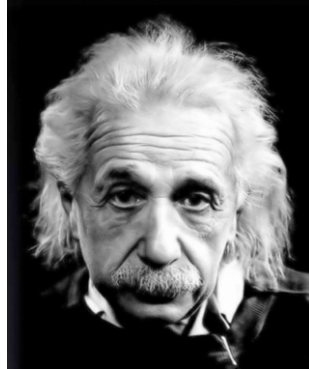


The Weird World of the Very Very Small



Introduction



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

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2

Introduction

A Sense of Scale
Metres → Nanometres

A Sense of Symmetry
Underlying Structure

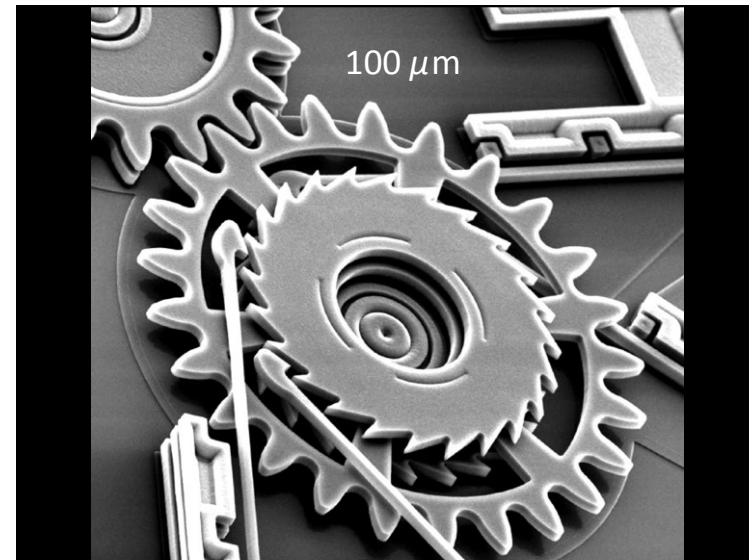
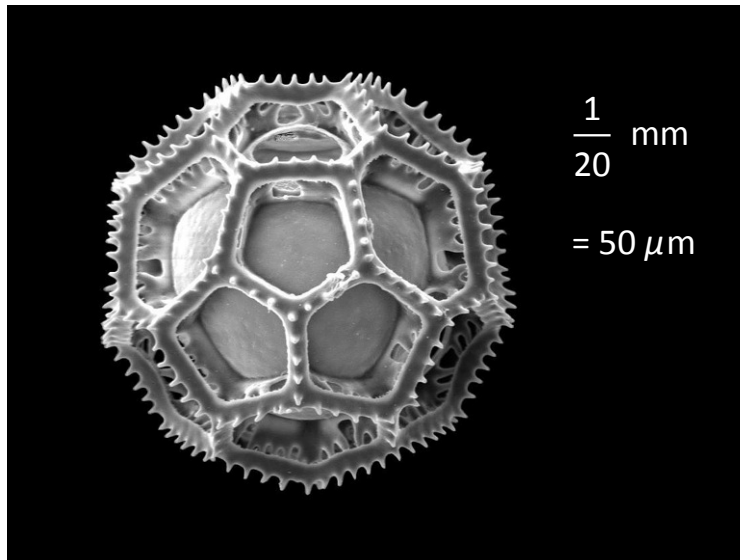
The Quantum World
Seeing Atoms

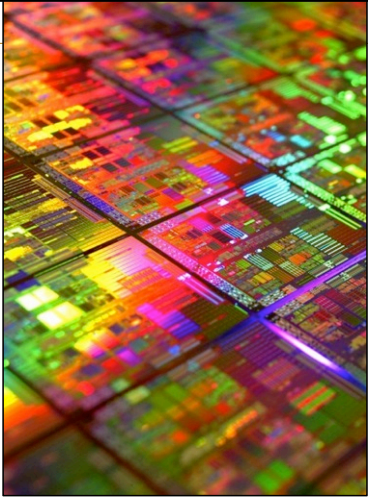
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3



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A Sense of Scale

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

10 million
transistors...


so size of
components
 $\sim 10\text{--}100 \text{ nm}$



7

Structure Within

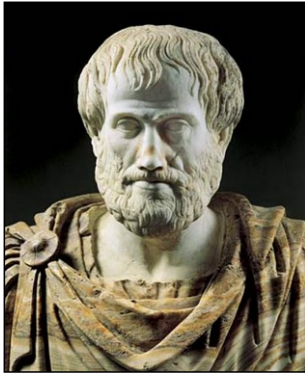
- What is the world made of?
- How can we tell?
- What clues do we have?



8

The Weird World of the Very Very Small

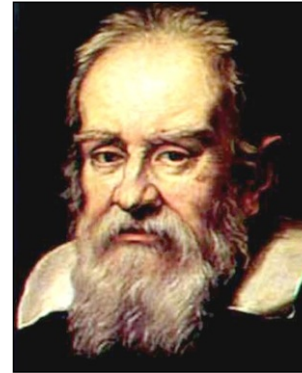
Aristotle



Elements

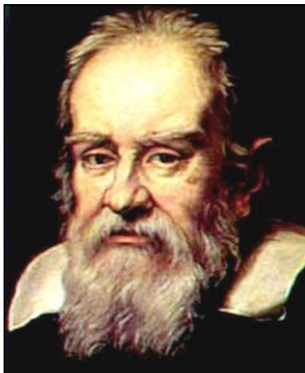
Fire
Air
Water
Earth

Galileo



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

Galileo



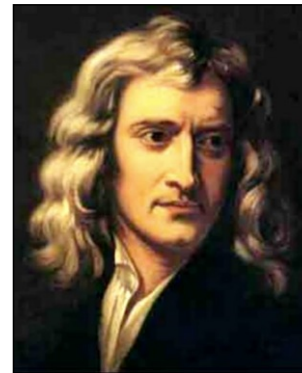
Ask not

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

but

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

Newton



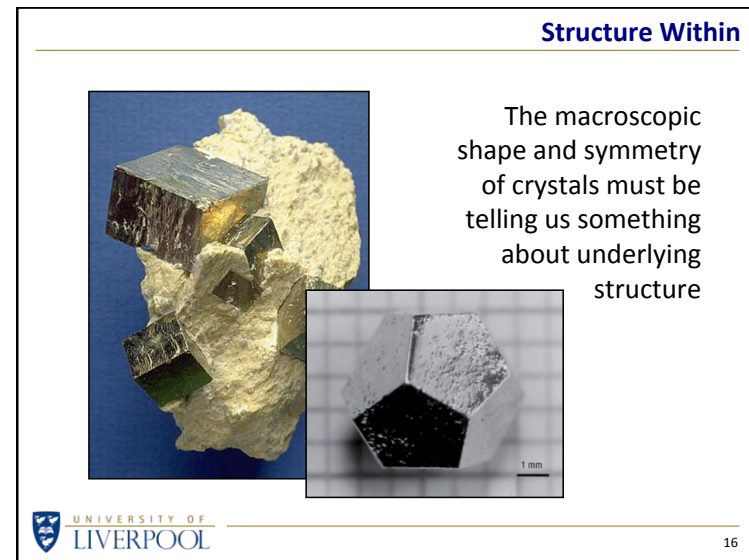
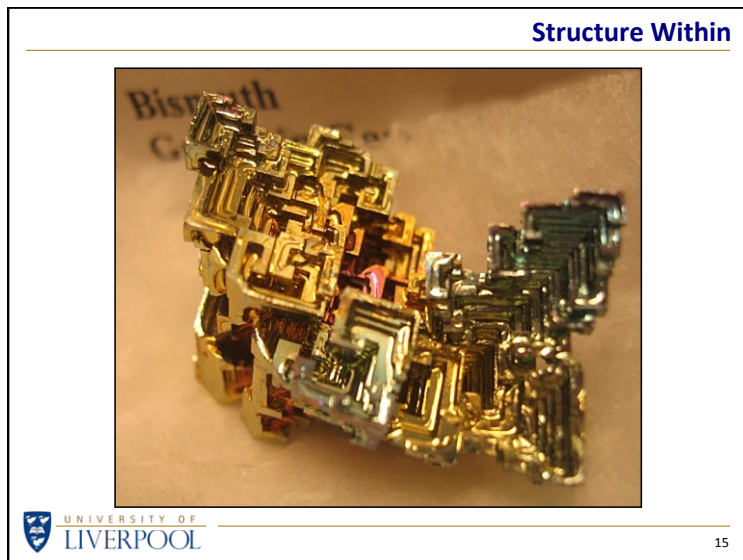
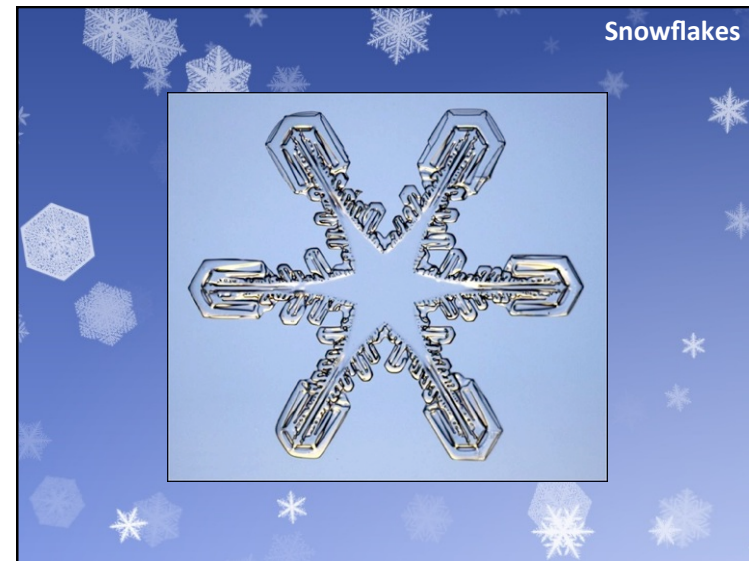
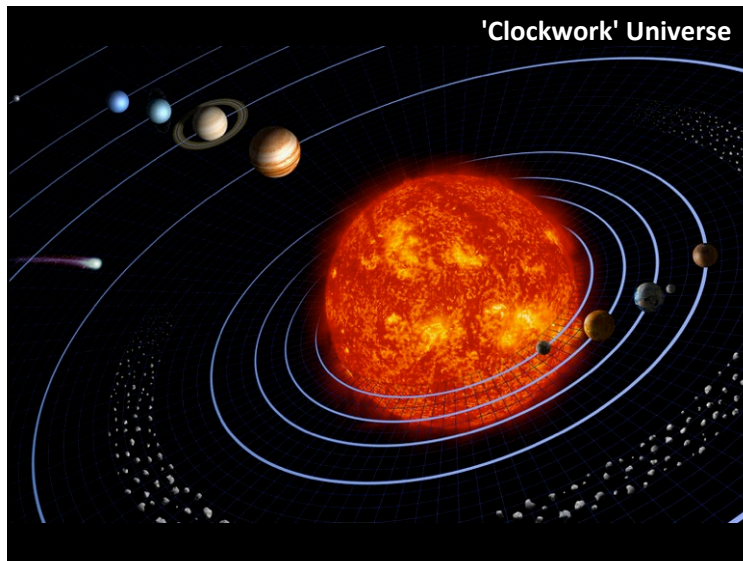
Laws of Motion

Law of Gravity

Nature of Light

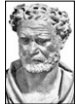







"Classical Mechanics"

The Weird World of the Very Very Small





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Atoms

1600		1700		1800		1900	
Democritus				Dalton		Maxwell	
							
							
			Lavoisier	Avogadro		Boltzmann	

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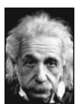



Particles and Waves

1800		1850		1900	
					

^ Light (Waves) ^ Electrons (Particles)

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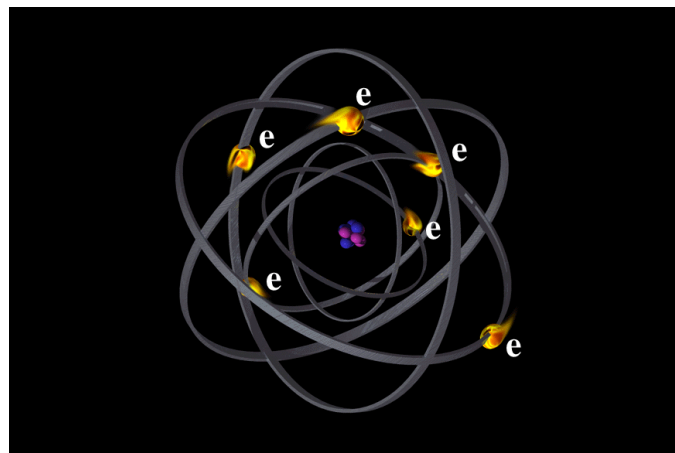
Atoms To Quantum Mechanics

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

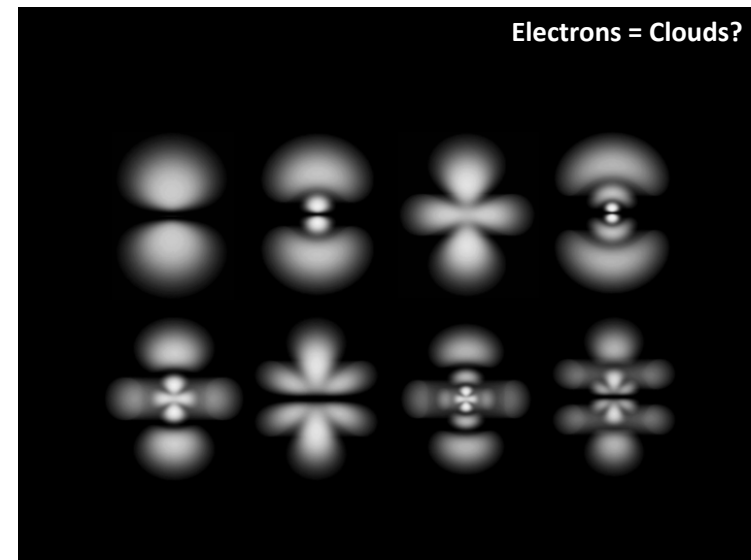
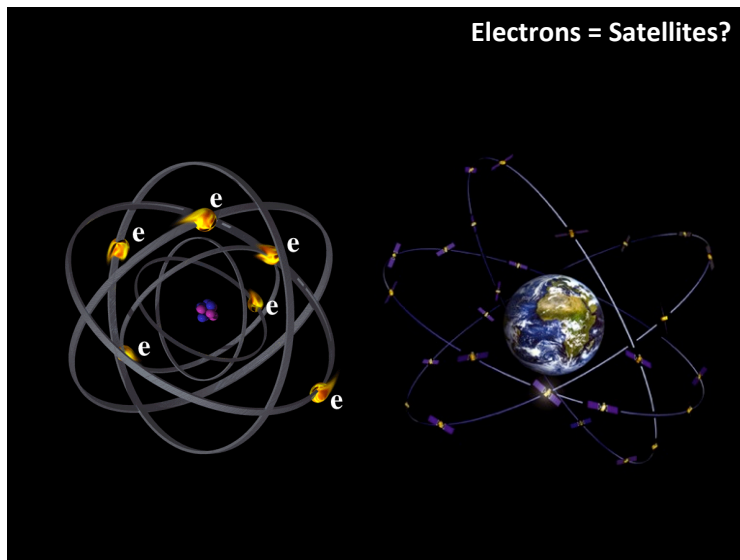
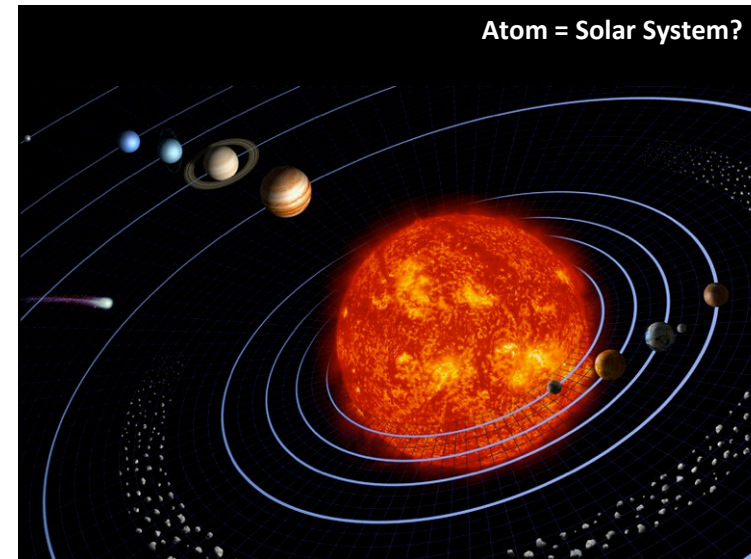


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The Weird World of the Very Very Small

PERIODIC TABLE of the ELEMENTS

DMITRI MENDELEEV (1834 - 1907)



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Dealing With Atoms

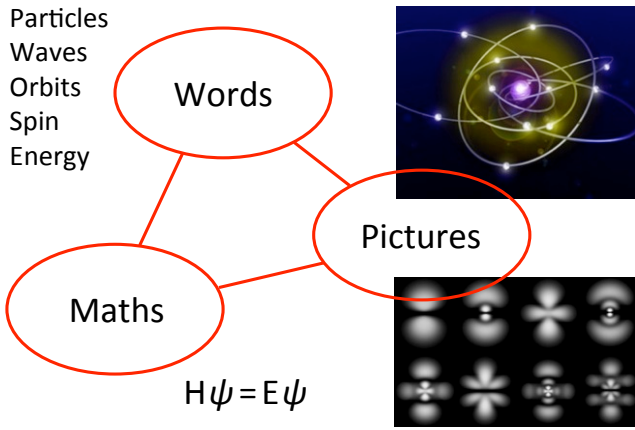
Particles
Waves
Orbits
Spin
Energy

Words

Maths

Pictures


$H\psi = E\psi$



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Heisenberg



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

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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"

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Bohr



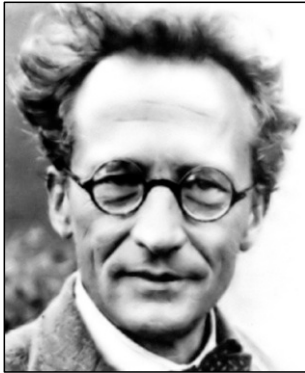
"Everything we call real is made of things that cannot be regarded as real"

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The 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 "

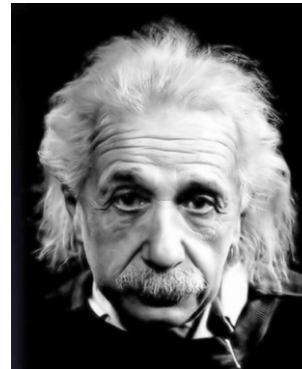
QM vs Common Sense

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



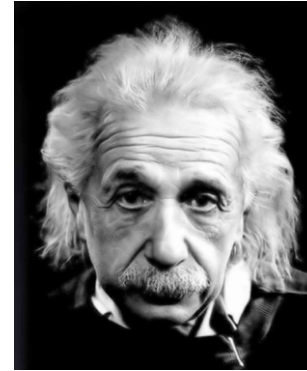
" Common sense is the collection of prejudices acquired by age eighteen "

The 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

The 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



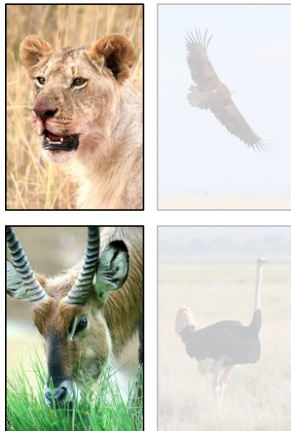
Top pair : carnivores

Bottom pair : veggies

Left pair : 4 legs

Right pair : wings

If Order Matters



Pick 2 out of the 4

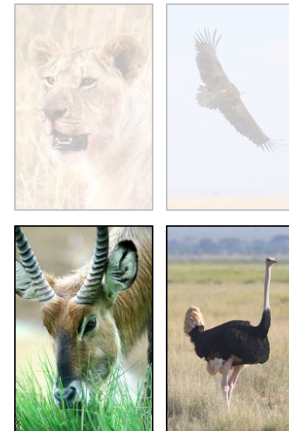
For instance, pick the **veggie** animals

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** ostrich!

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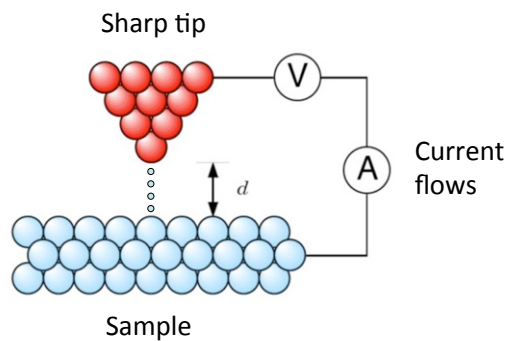
Schrödinger's Cat



How Do We Know QM Is Right?

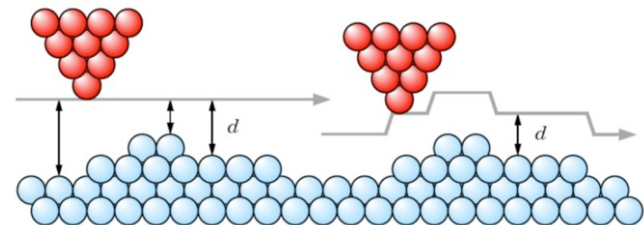
- So far, nothing has proved it wrong
- Quantum Mechanics predicts results that are impossible by 'Classical Mechanics'
- Using QM theory, we can build a microscope that can 'see' atoms

Scanning Tunnelling Microscope



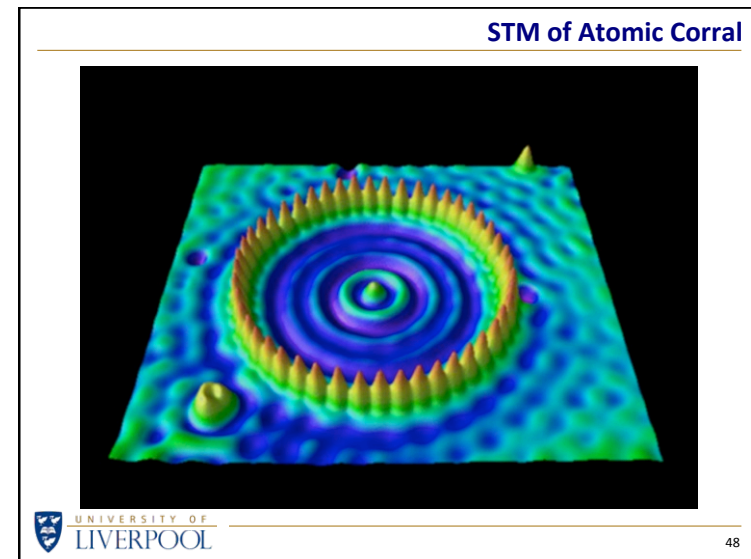
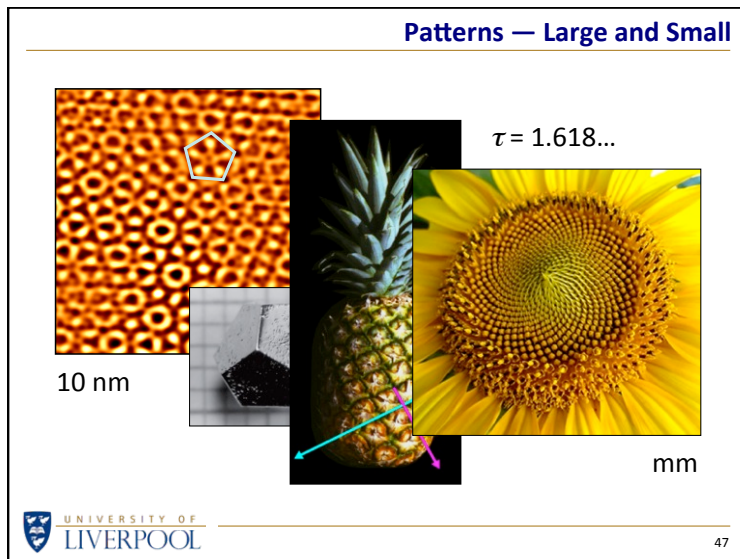
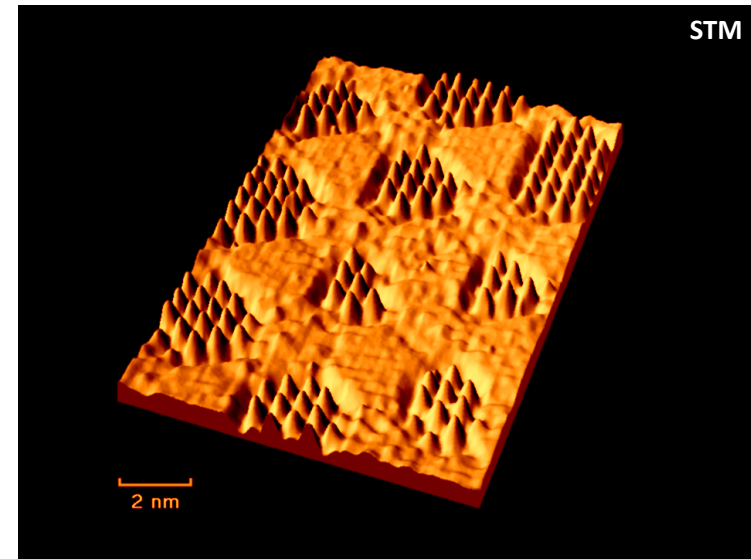
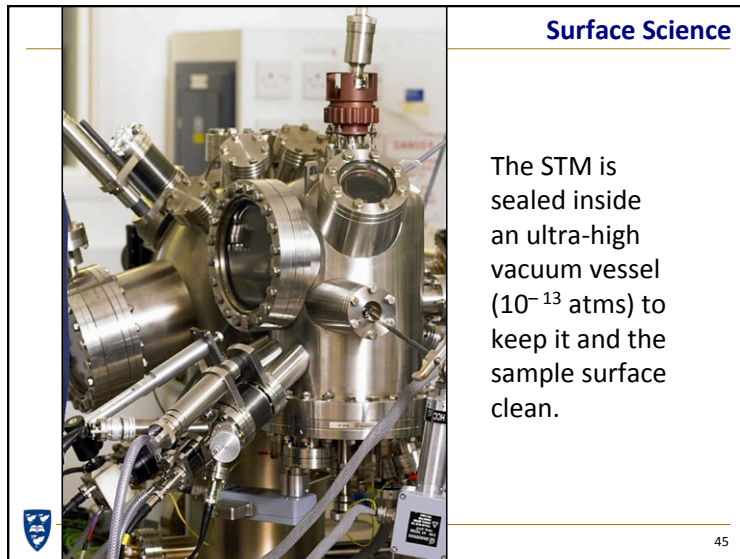
STM

Move tip across sample...



...measuring current at each point

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Bohr

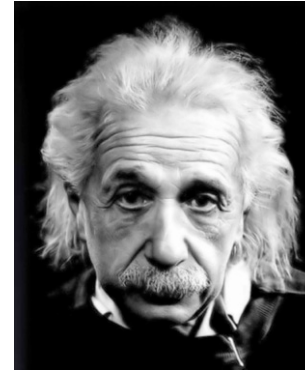


"If quantum mechanics hasn't profoundly shocked you, you haven't understood it"



49

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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The Weird World
of the
Very
Very
Small

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

Dr Steve Barrett
SCAS
15 Oct 2020