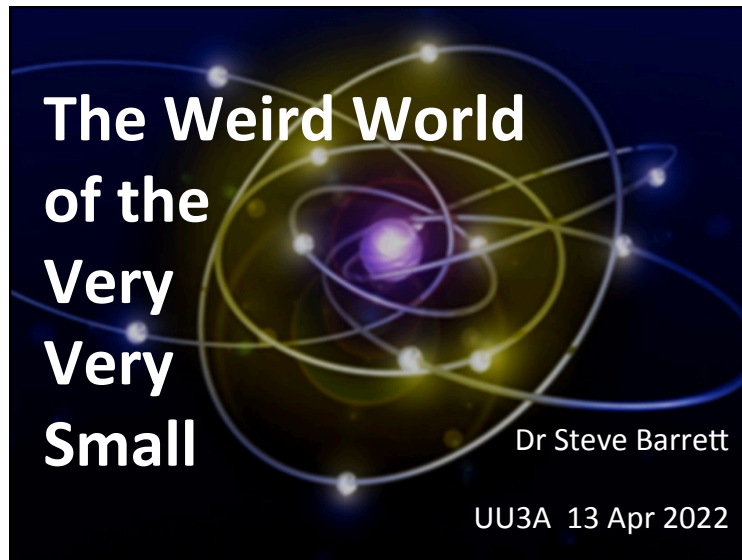
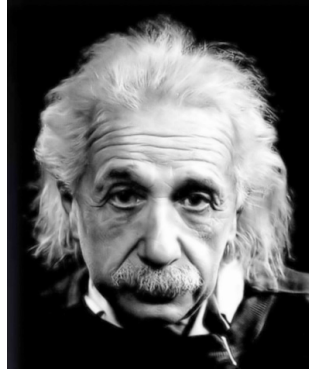


# The Weird World of the Very Very Small



**Introduction**



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

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**Introduction**

**A Sense of Scale**  
Metres → Nanometres

**A Sense of Symmetry**  
Underlying Structure

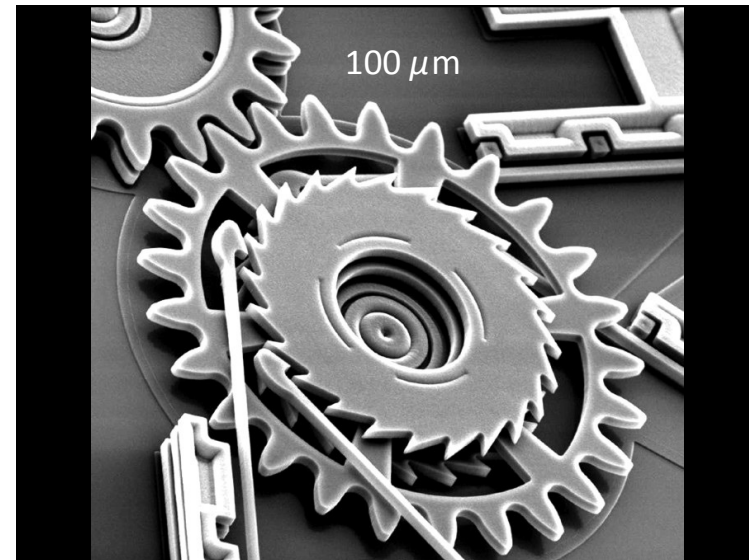
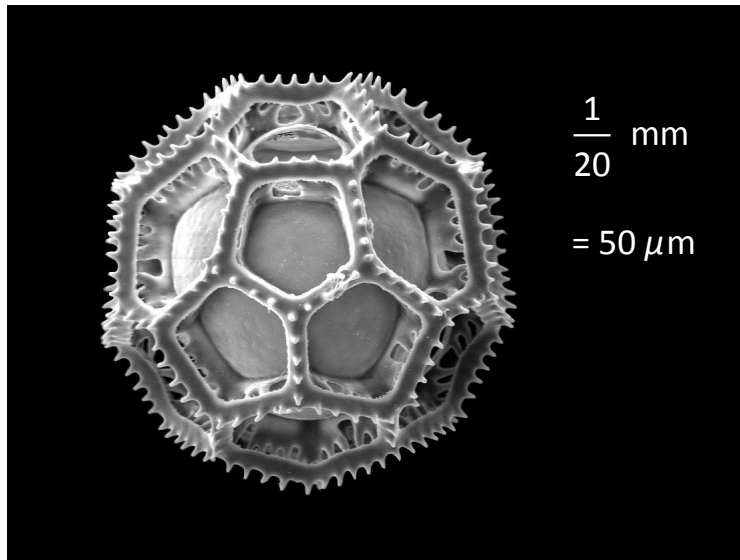
**The Quantum World**  
Seeing Atoms

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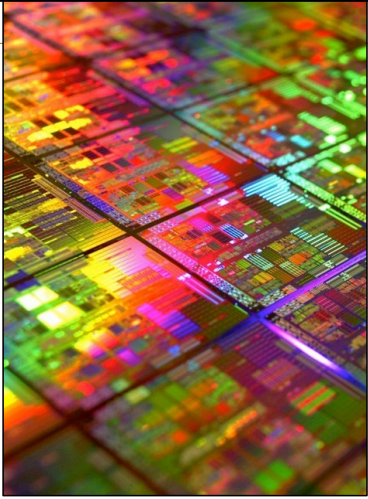
3



# The Weird World of the Very Very Small



**A Sense of Scale**



Microprocessor  
chip area  $\sim$  mm<sup>2</sup> ...

10 million  
transistors...

so size of  
components  
 $\sim$  10–100 nm

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**Structure Within**

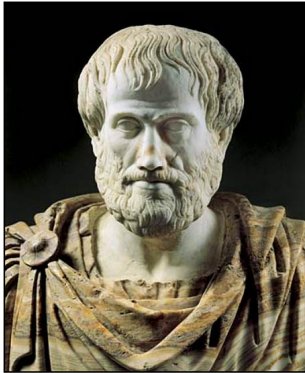
- What is the world made of?
- How can we tell?
- What clues do we have?

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# The Weird World of the Very Very Small

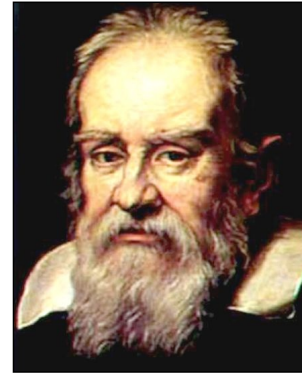
Aristotle



## Elements

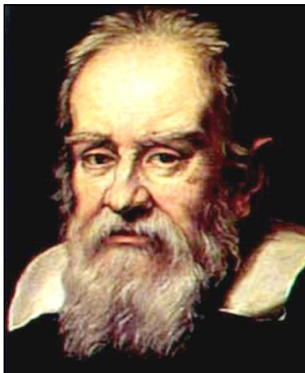
Fire  
Air  
Water  
Earth

Galileo



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

Galileo



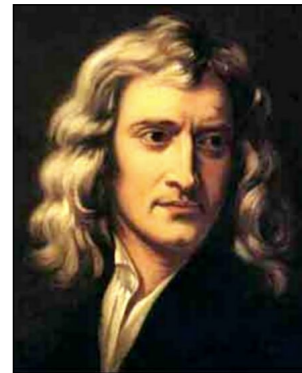
Ask not

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

but

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

Newton



Laws of Motion

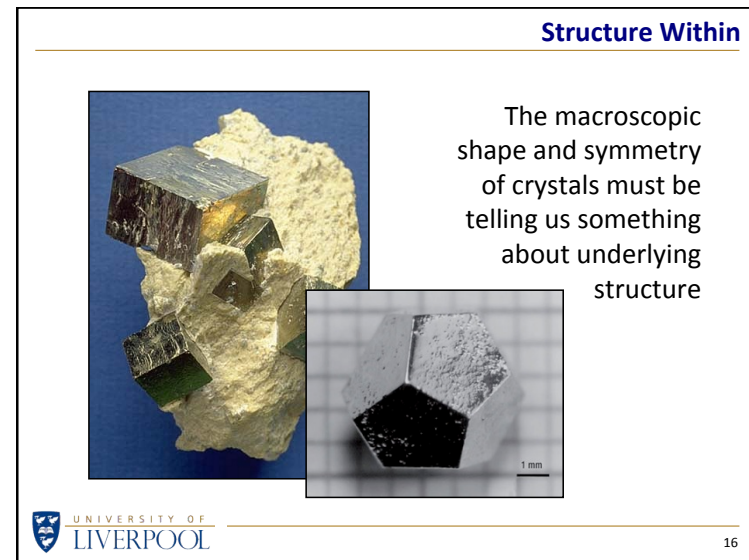
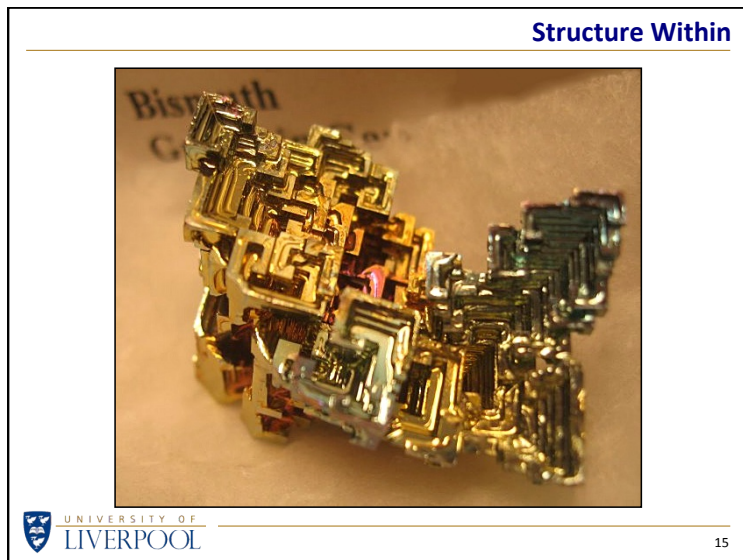
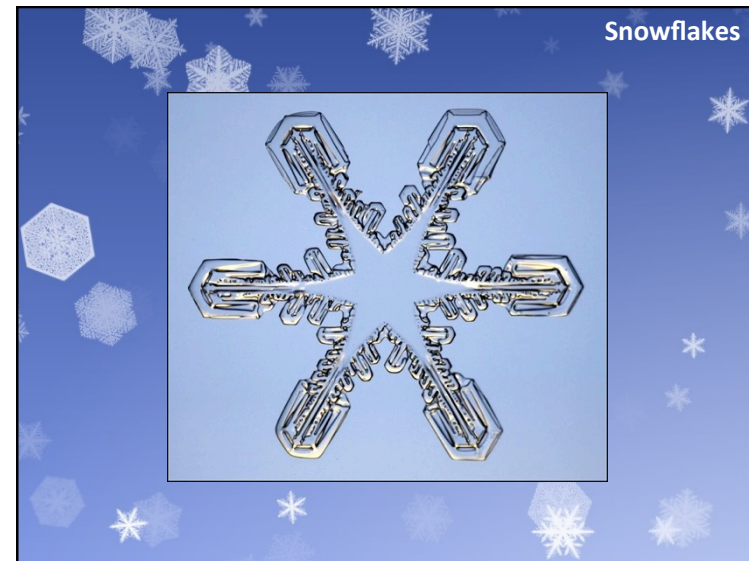
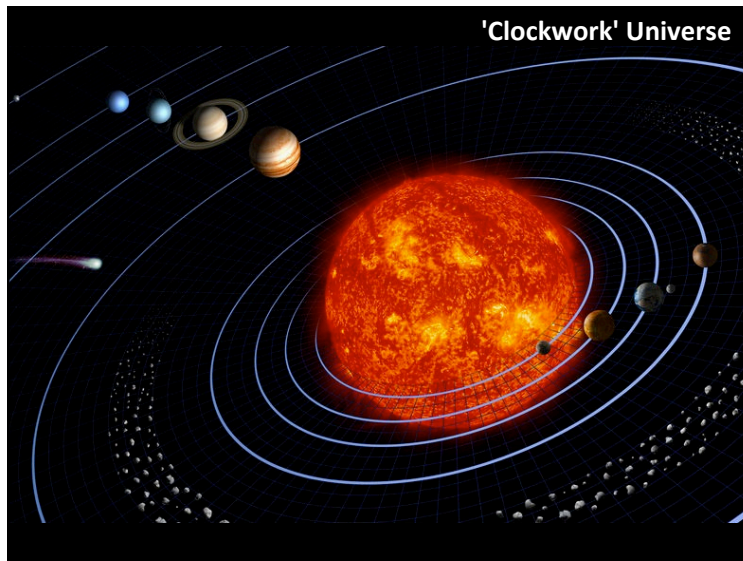
Law of Gravity

Nature of Light

"Classical Mechanics"

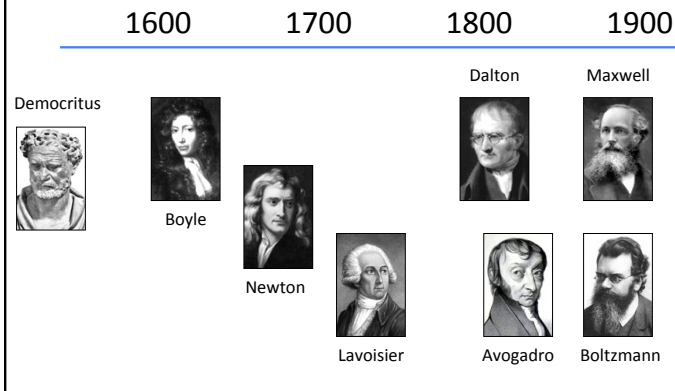


# The Weird World of the Very Very Small



# The Weird World of the Very Very Small

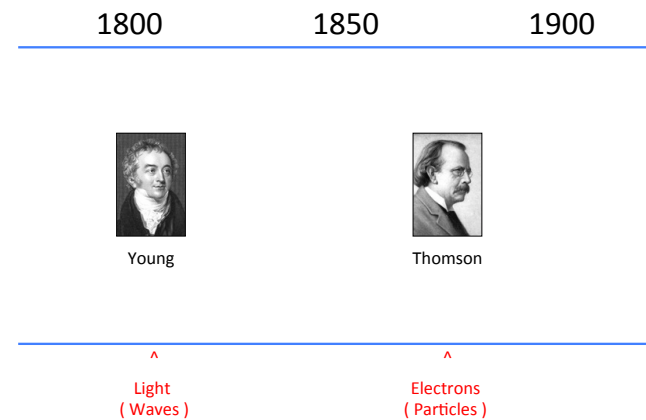
## Atoms



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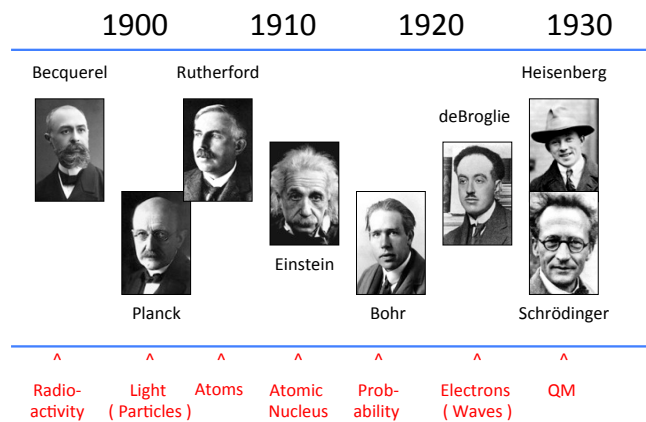
## Particles and Waves



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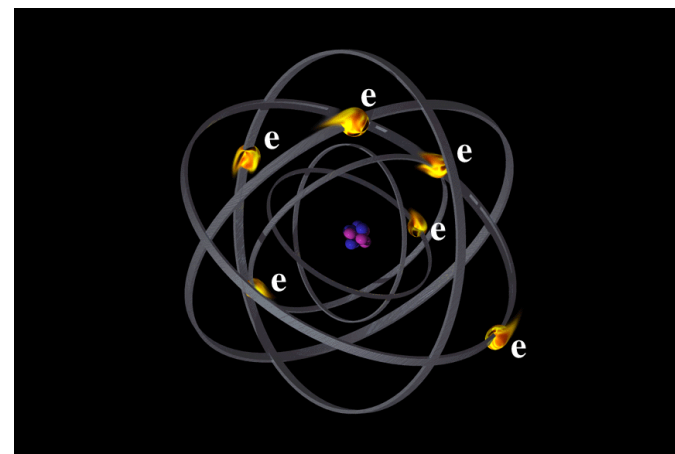
## Atoms To Quantum Mechanics



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## Bohr Model



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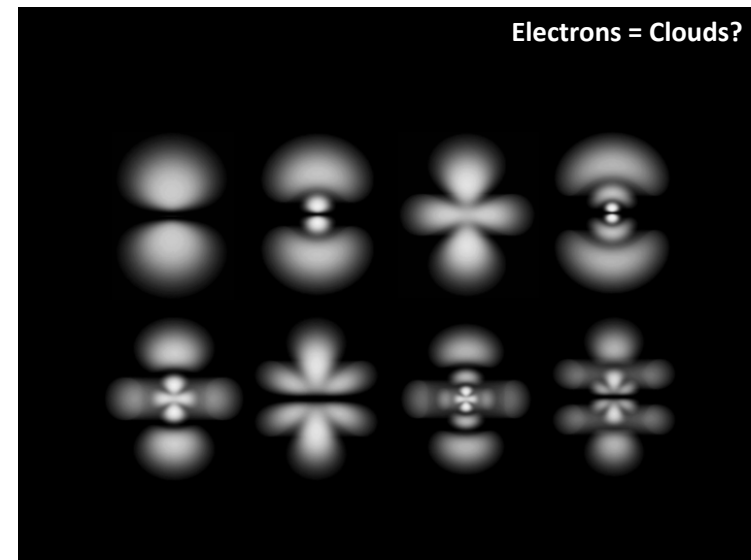
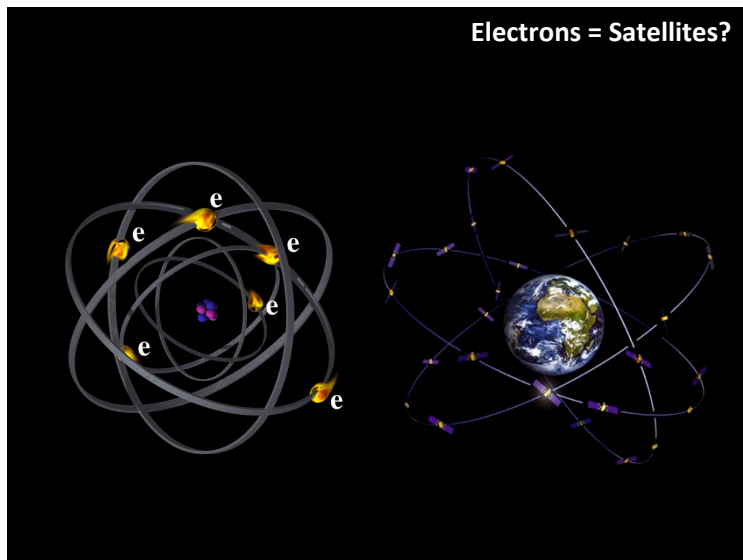
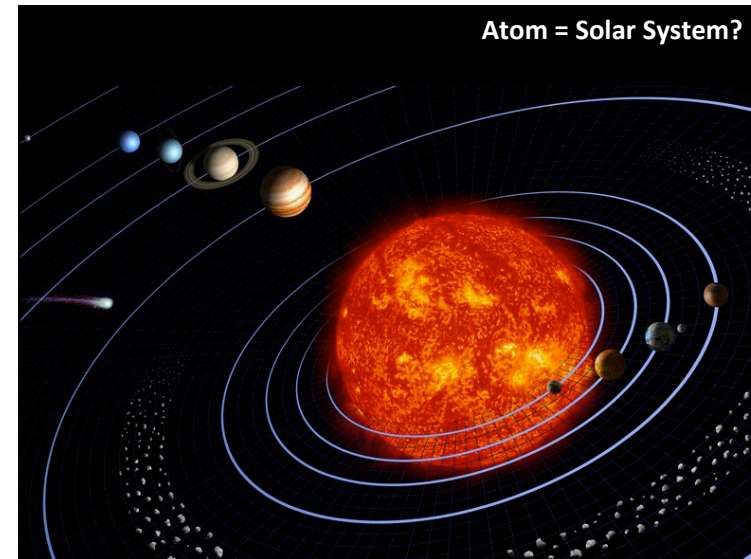
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# The Weird World of the Very Very Small

PRODUCED BY THE FOUNDATION FOR EXPEDITION, SCIENCE AND TECHNOLOGY FOR NATIONAL SET WEEK 2002

## PERIODIC TABLE of the ELEMENTS

DMITRI MENDELEEV (1834 - 1907)



# The Weird World of the Very Very Small

**Dealing With Atoms**

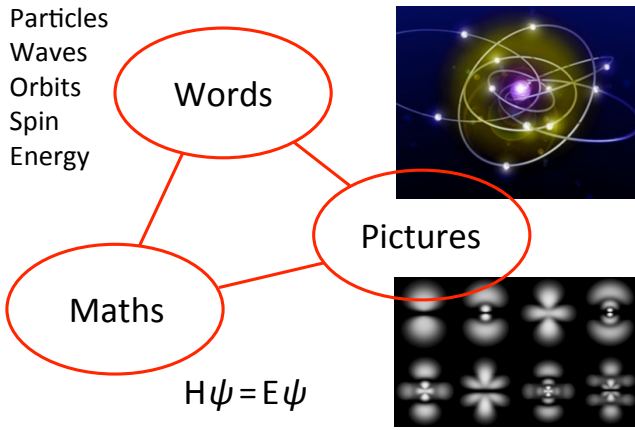
Particles  
Waves  
Orbits  
Spin  
Energy

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"

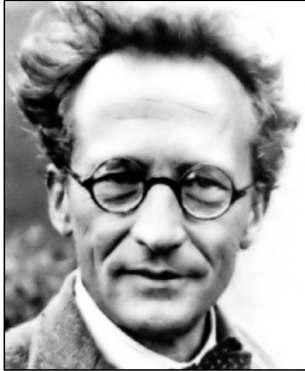
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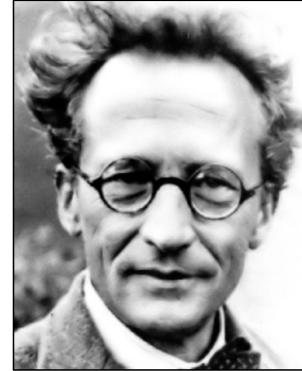
# The Weird World of the Very Very Small

## 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 "

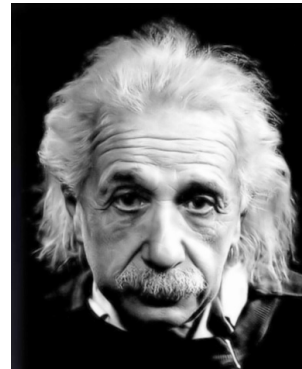
## QM vs Common Sense

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 "

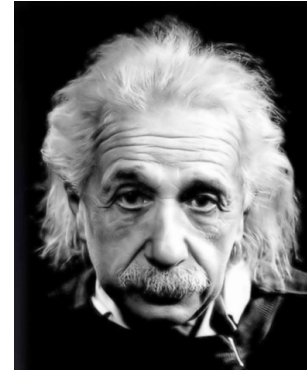


# The Weird World of the Very Very Small

## 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



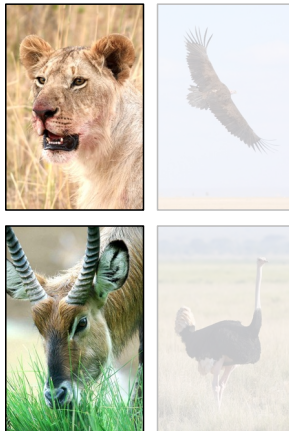
Top pair : carnivores

Bottom pair : veggies

Left pair : 4 legs

Right pair : wings

## If Order Matters



Pick 2 out of the 4

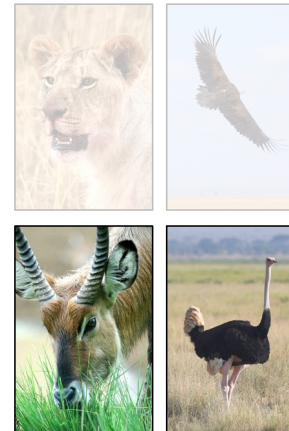
For instance, pick the **veggie** animals

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!

# The Weird World of the Very Very Small

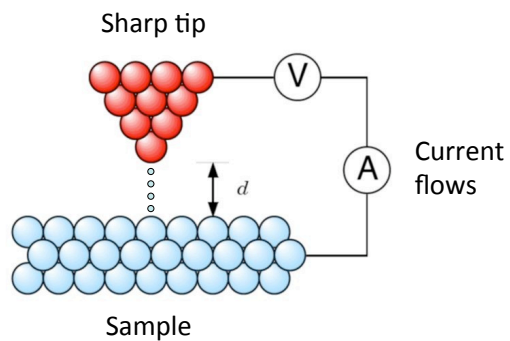
## Schrödinger's Cat



## How Do We Know QM Is Right?

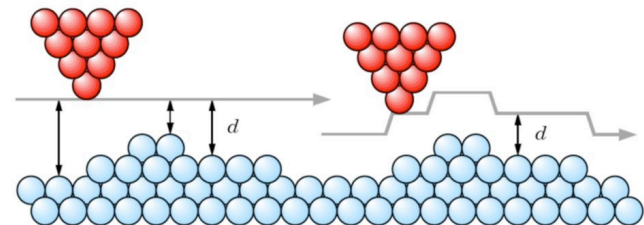
- So far, nothing has proved it wrong
- Quantum Mechanics predicts results that are impossible by 'Classical Mechanics'
- Using QM theory, we can build a microscope that can 'see' atoms

## Scanning Tunnelling Microscope



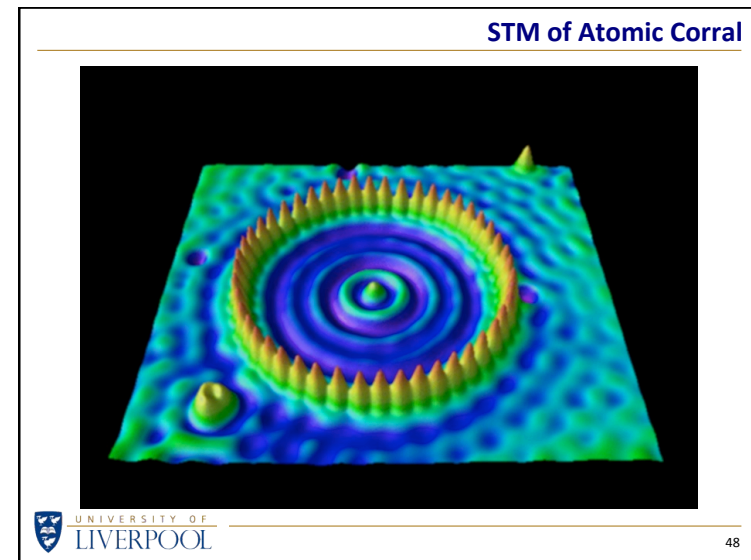
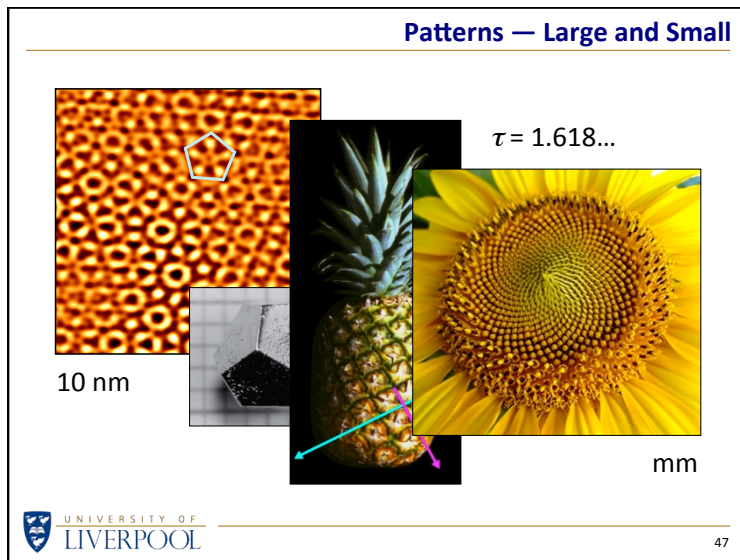
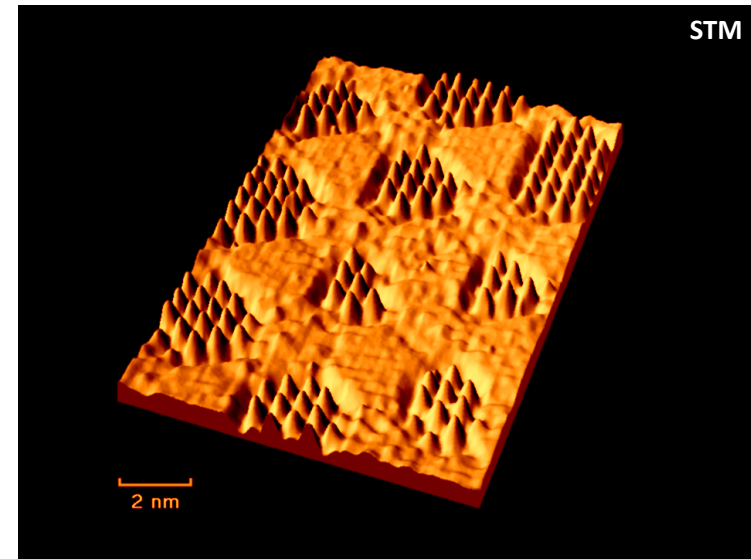
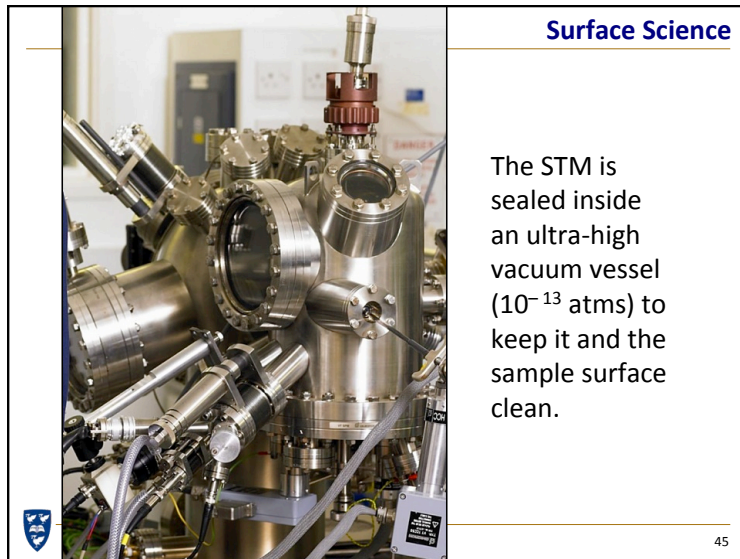
## STM

Move tip across sample...



...measuring current at each point

# The Weird World of the Very Very Small





# The Weird World of the Very Very Small

Bohr

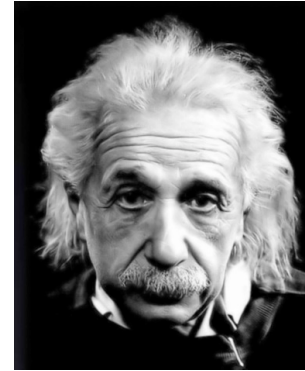


"If quantum mechanics hasn't profoundly shocked you, you haven't understood it"



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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](http://www.liverpool.ac.uk/~sdb/Talks)

Dr Steve Barrett  
UU3A  
13 Apr 2022