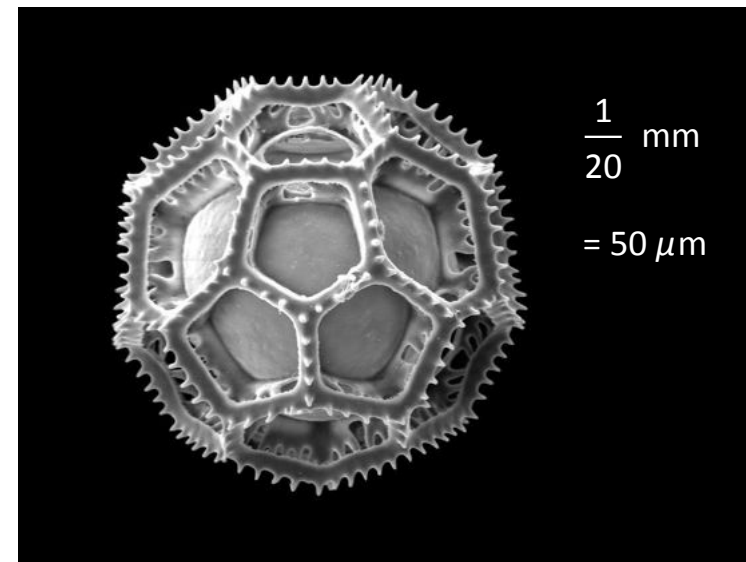
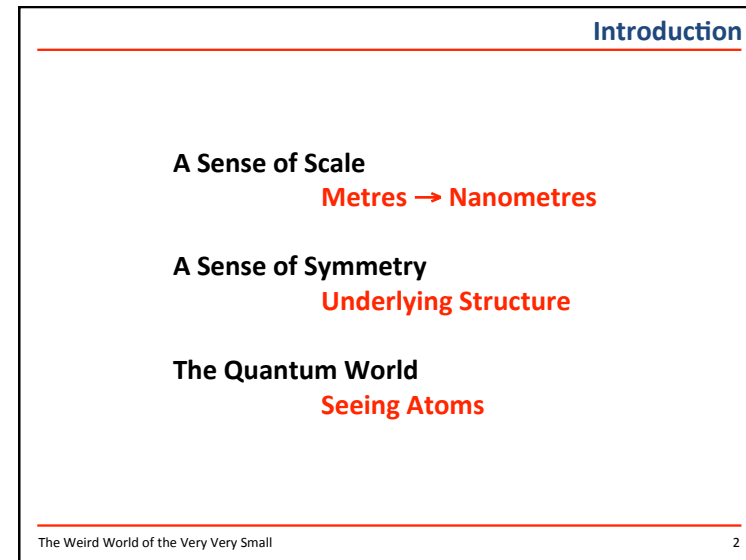
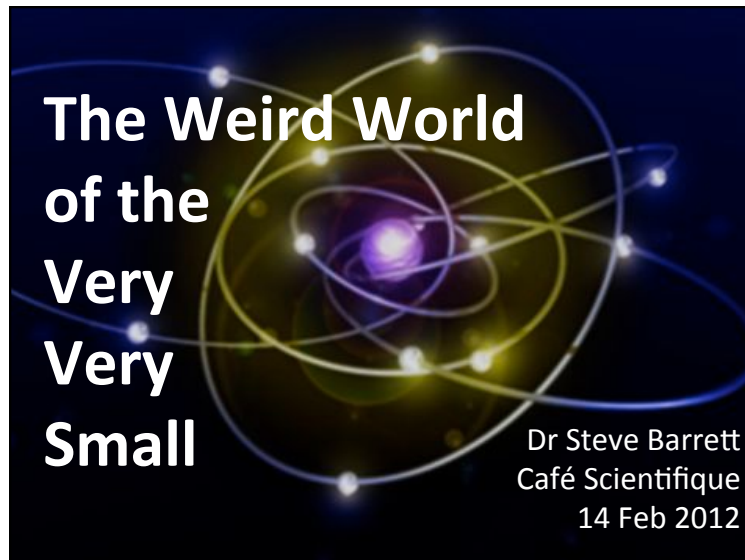
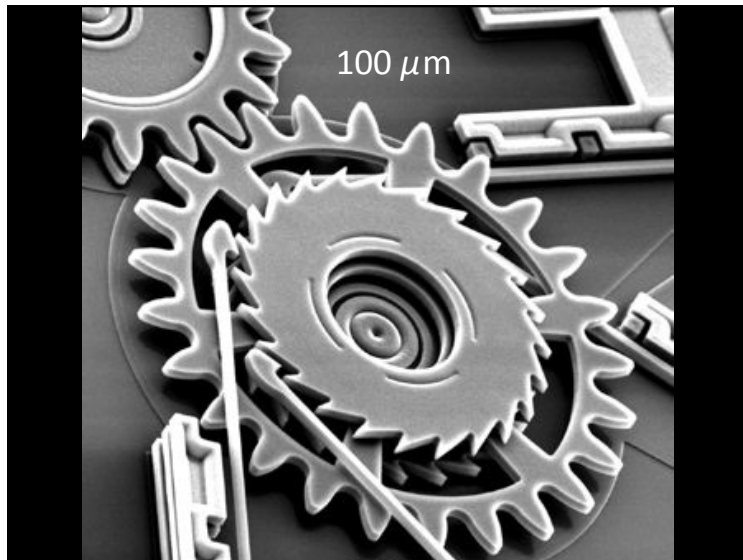
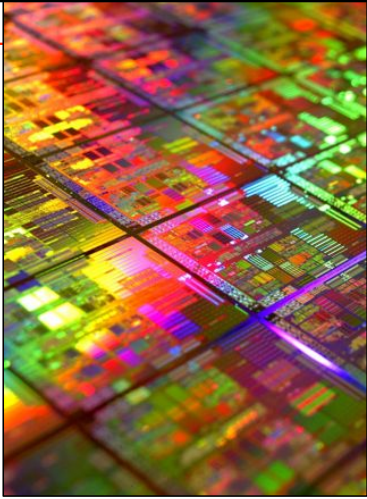


# The Weird World of the Very Very Small



# The Weird World of the Very Very Small



A photograph of a microprocessor chip, showing its intricate circuitry and various components. The chip is square and has a complex, multi-colored pattern of circuitry.

### A Sense of Scale

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

10 million  
transistors...

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

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### Structure Within

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

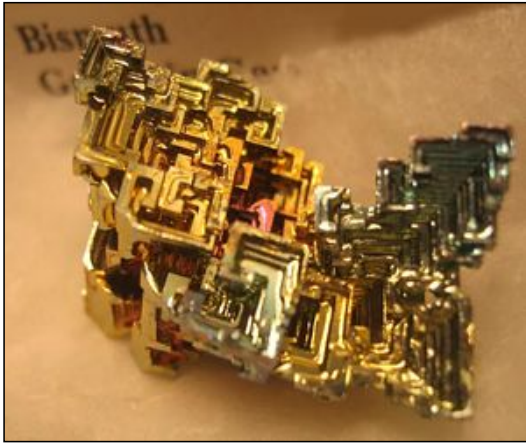
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# The Weird World of the Very Very Small

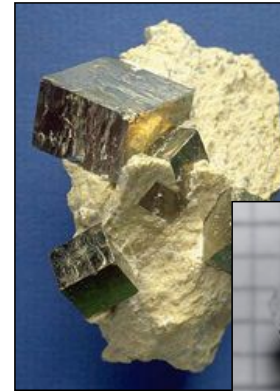
## Structure Within



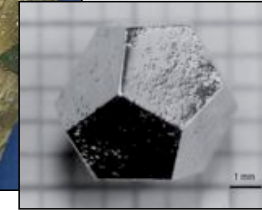
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## Structure Within



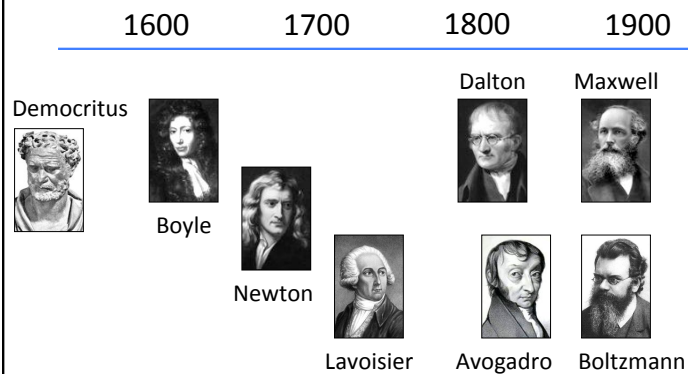
The macroscopic shape and symmetry of crystals must be telling us something about underlying structure



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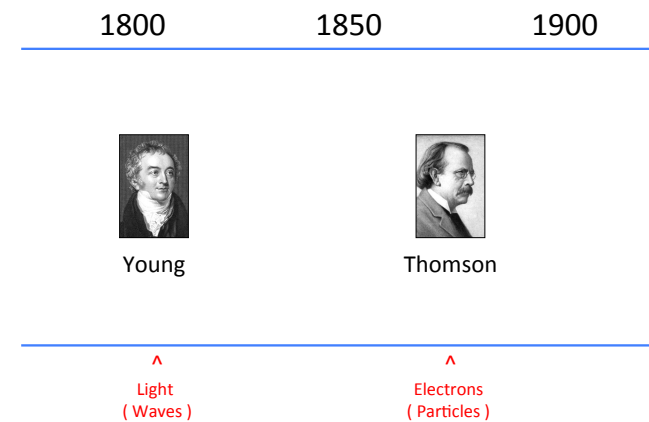
## Atoms



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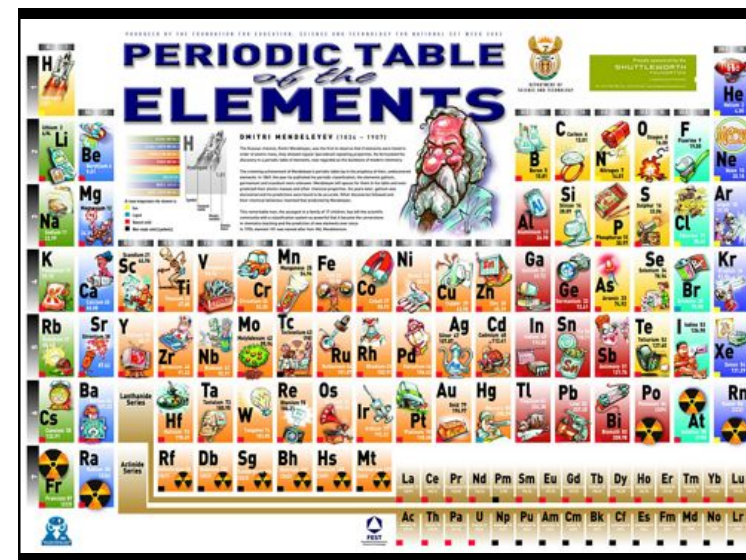
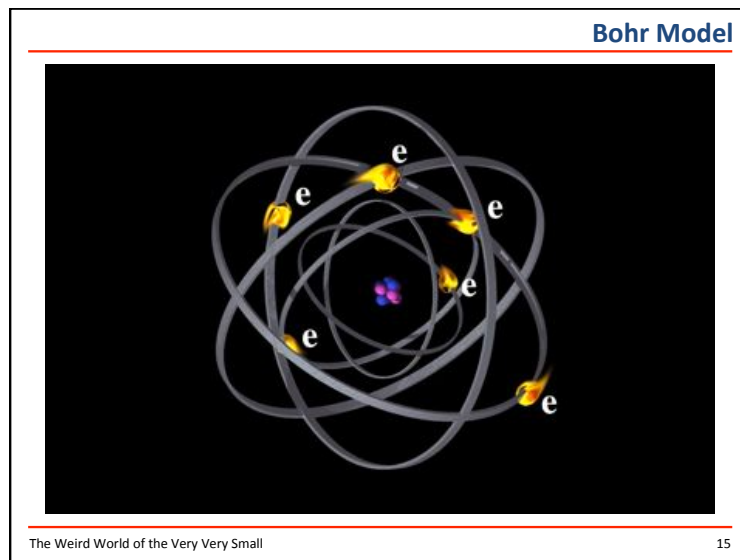
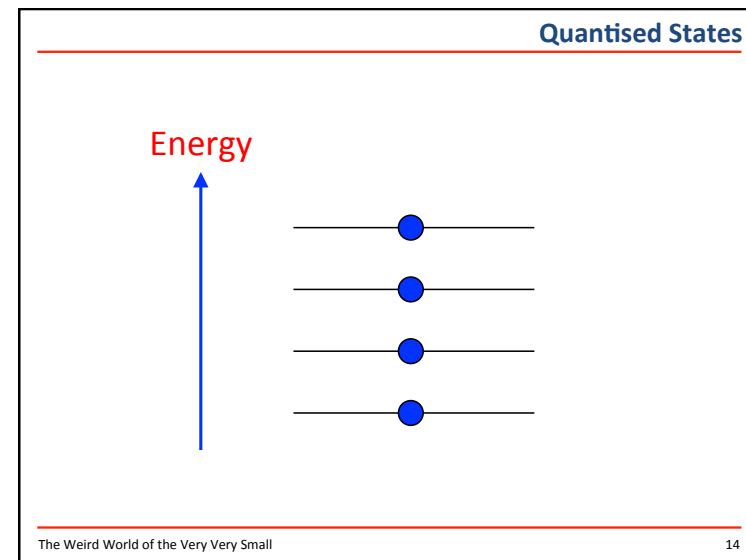
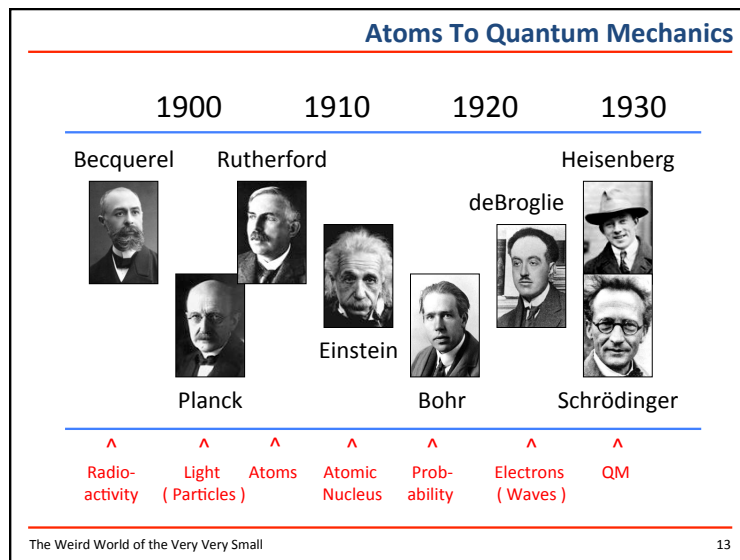
## Particles and Waves



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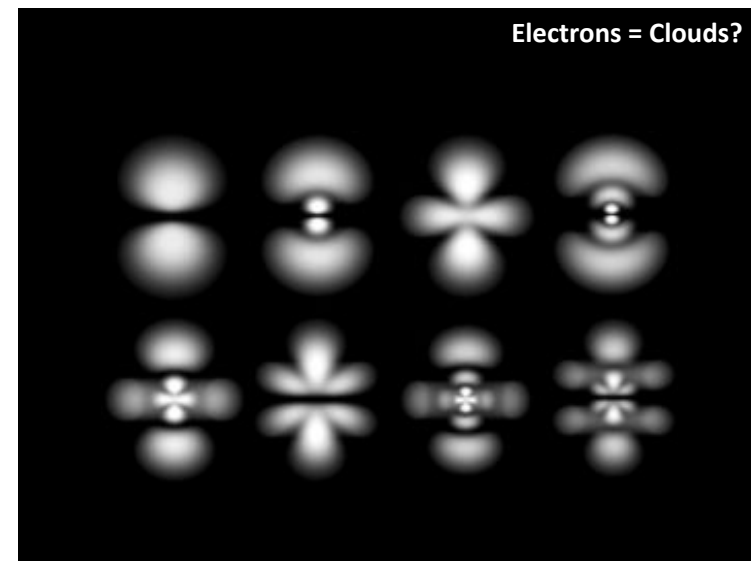
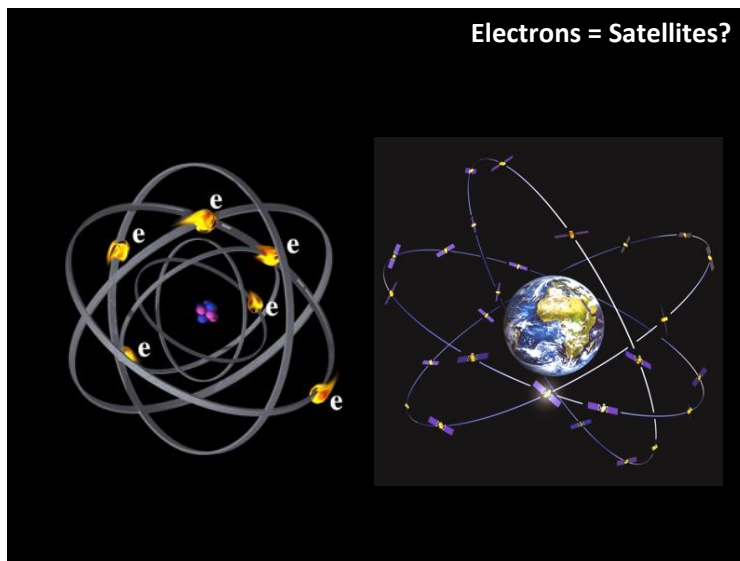
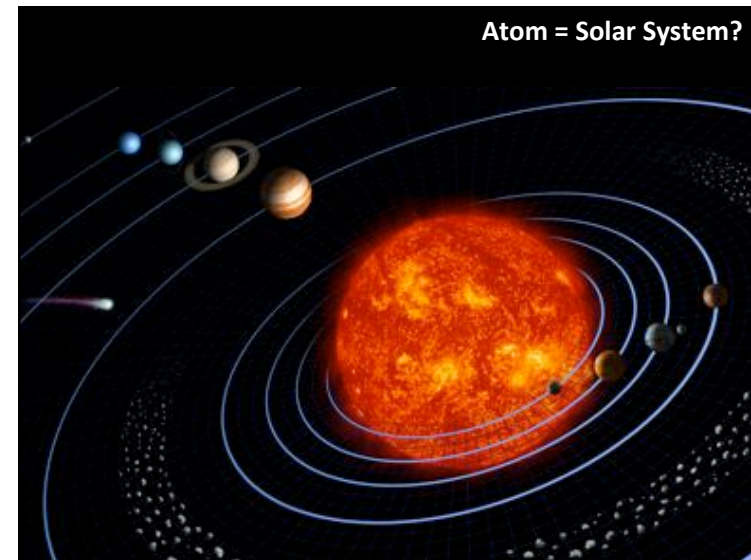
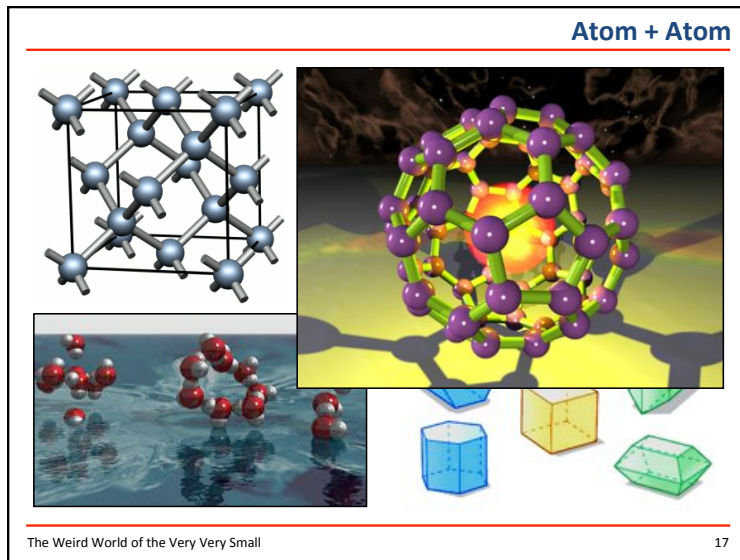
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# The Weird World of the Very Very Small





# The Weird World of the Very Very Small



# The Weird World of the Very Very Small

Dealing With Atoms

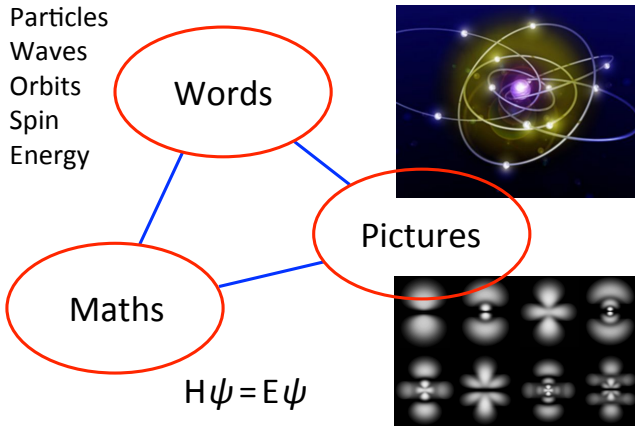
Particles  
Waves  
Orbits  
Spin  
Energy

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 ”

The Weird World of the Very Very Small 22

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”

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## Schrödinger



“I don't like it, and I'm sorry I ever had anything to do with it”

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## 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, ...*

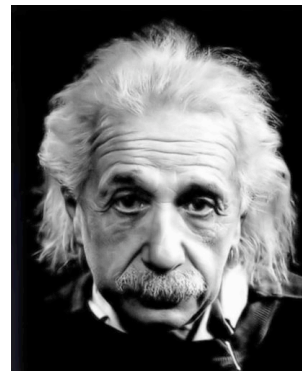
Atoms do not have a finite size:  
*An electron 'in' an atom could be **anywhere***

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”

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# The Weird World of the Very Very Small

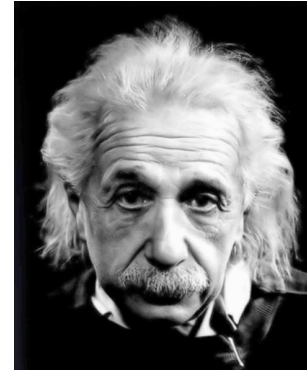
## Heads or Tails?



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## Einstein



“God does not play dice”

“God is subtle but he is not malicious”

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## Bohr



“Stop telling God what to do!”

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## Three Aspects of QM

- Order matters
- Schrödinger's Cat
- Using QM to see atoms

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# 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?

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## If Order Matters



Top pair : carnivores

Bottom pair : veggies

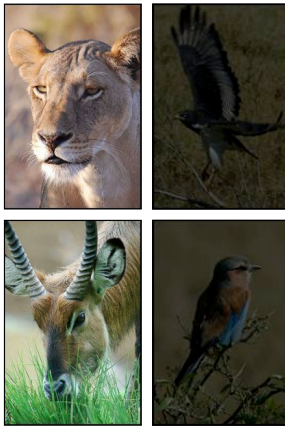
Left pair : 4 legs

Right pair : wings

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## If Order Matters



Pick 2 out of the 4

For instance, pick the **veggie** animals

From these, pick again

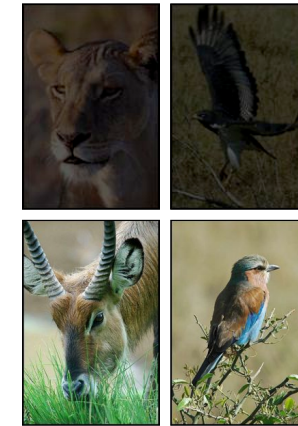
For instance, pick the **4-legged** animals

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** roller!

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# The Weird World of the Very Very Small

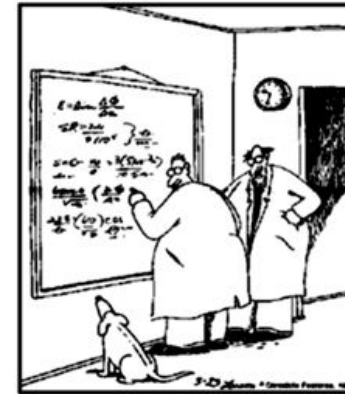
## Schrödinger's Cat



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## QM and Dogs



"Ohhh, look at that...  
dogs are so cute  
when they try to  
comprehend  
quantum  
mechanics"

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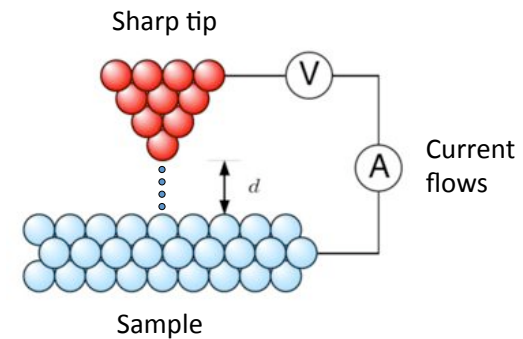
## How Do We Know QM Is Right?

- 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

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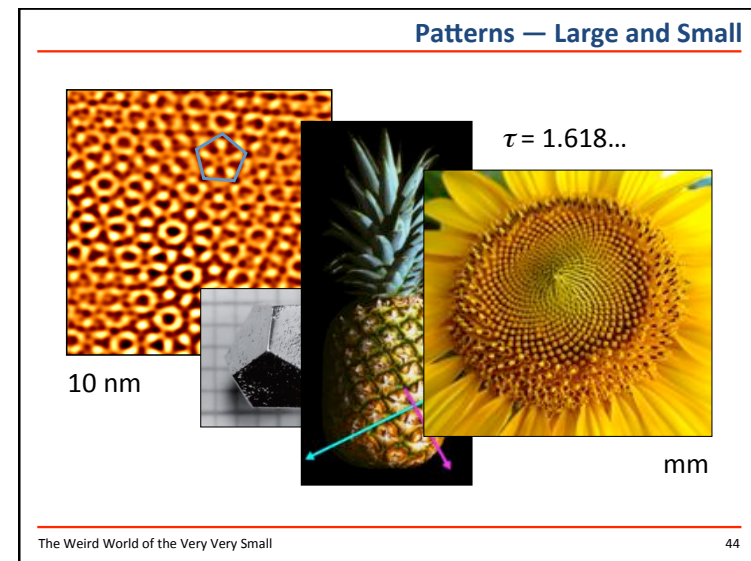
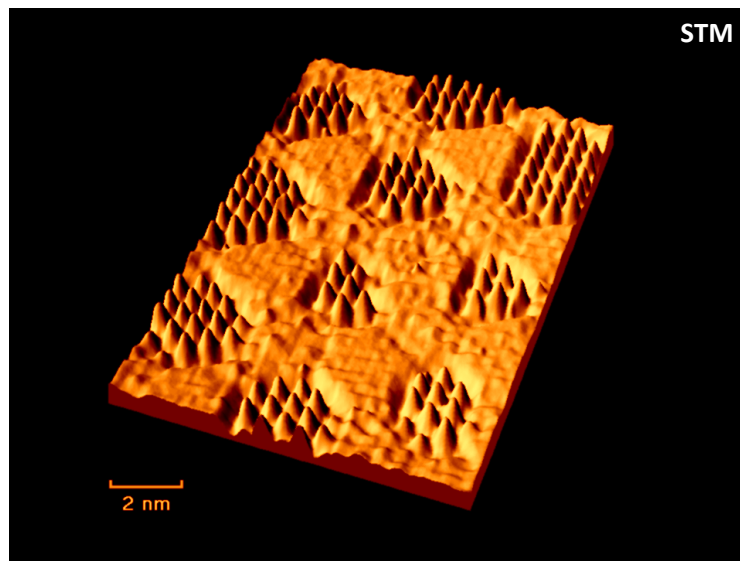
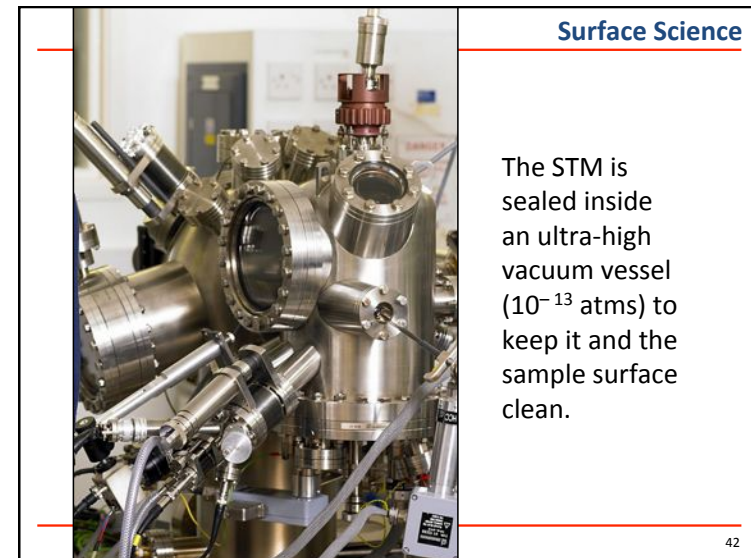
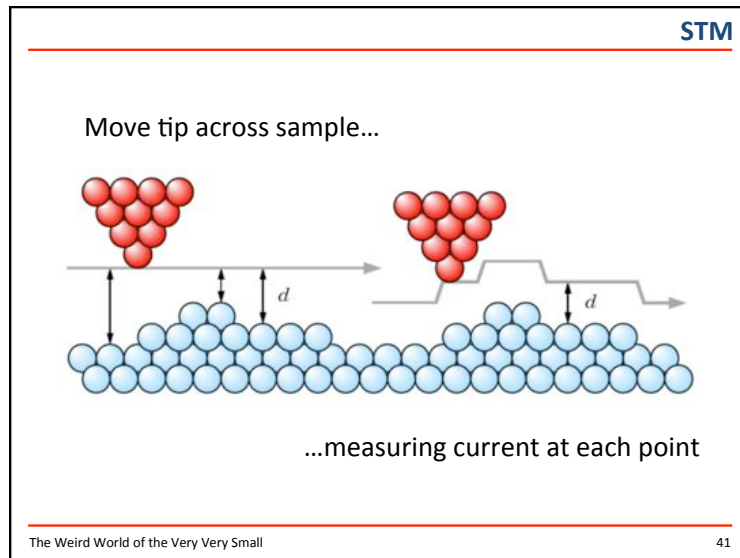
## Scanning Tunnelling Microscope



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# The Weird World of the Very Very Small



# The Weird World of the Very Very Small

Bohr

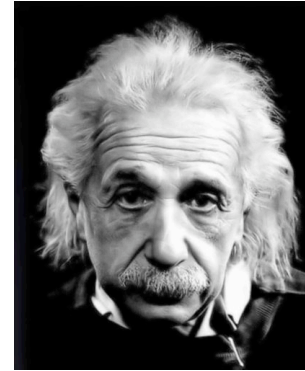


“If quantum mechanics hasn't profoundly shocked you, you haven't understood it”

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Einstein



“The most incomprehensible thing about the world is that it is comprehensible”

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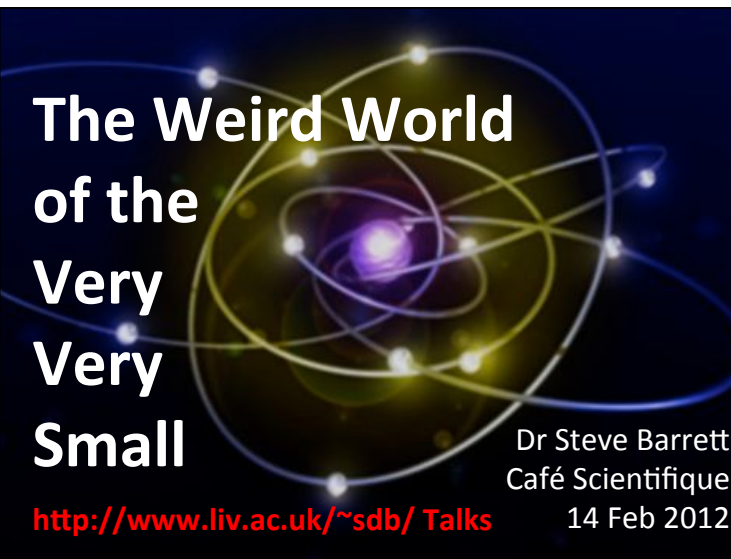
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William Blake

*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  
Café Scientifique  
14 Feb 2012

<http://www.liv.ac.uk/~sdb/Talks>