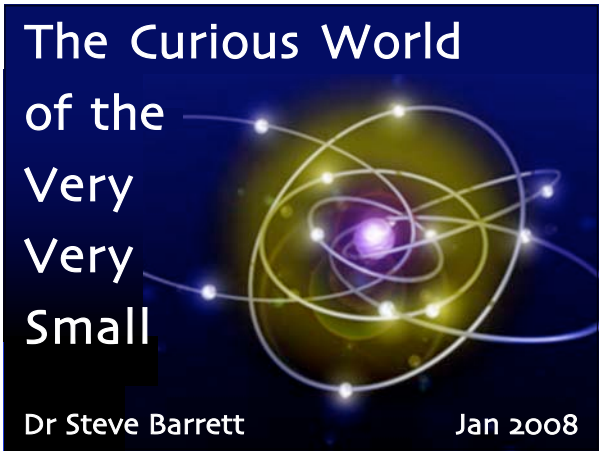
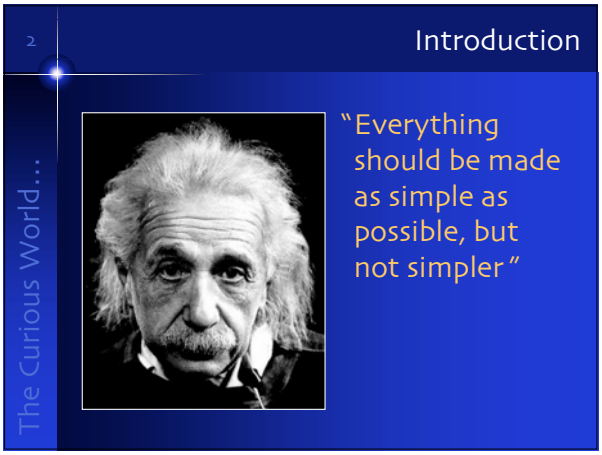
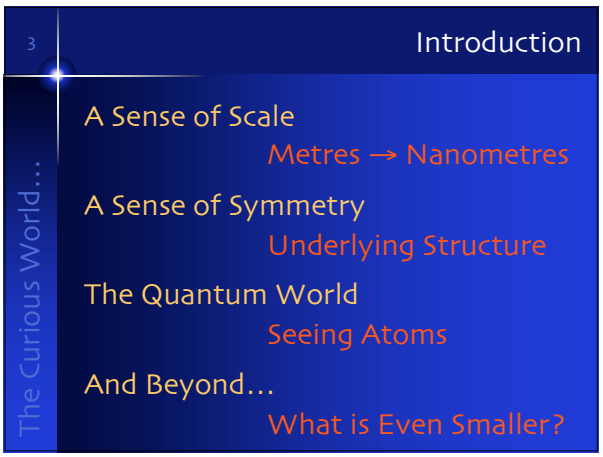
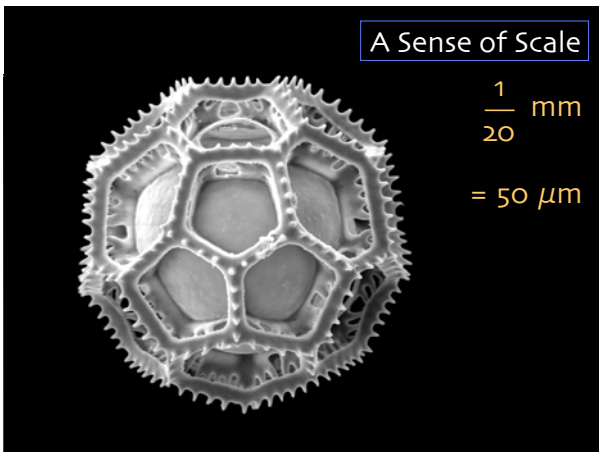
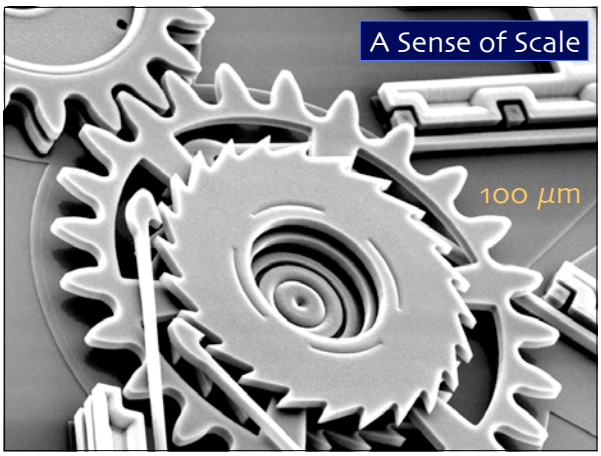
The Curious World of the Very Very Small



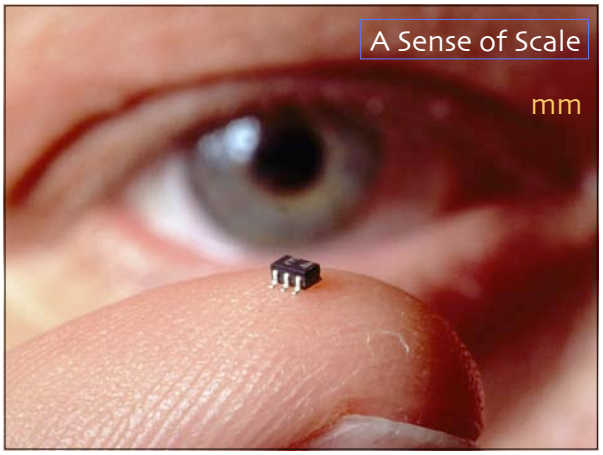


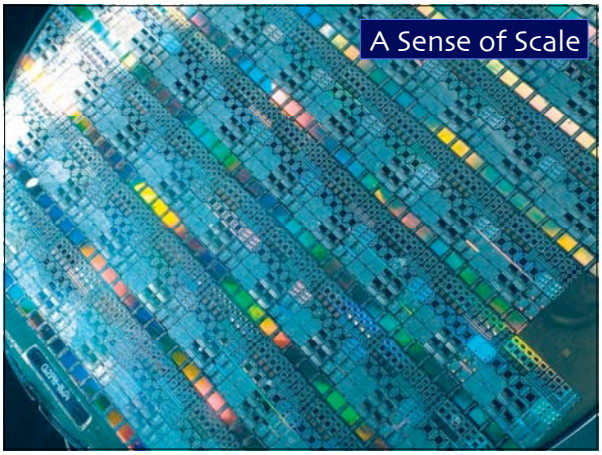


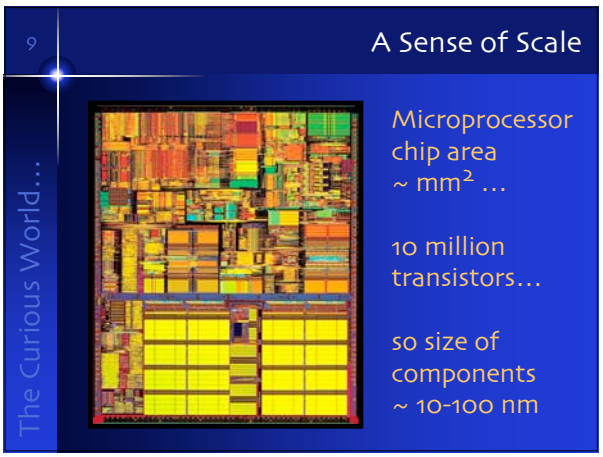


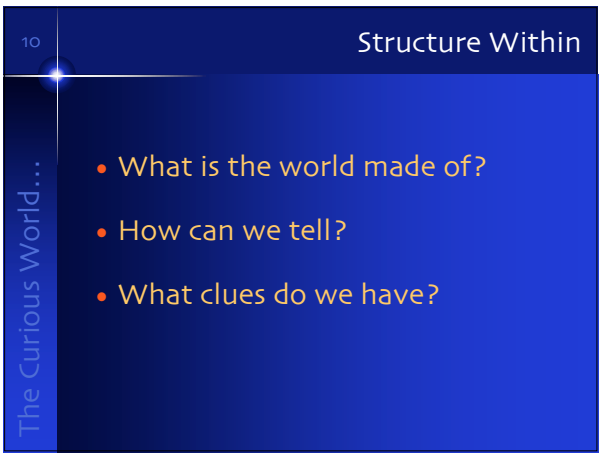


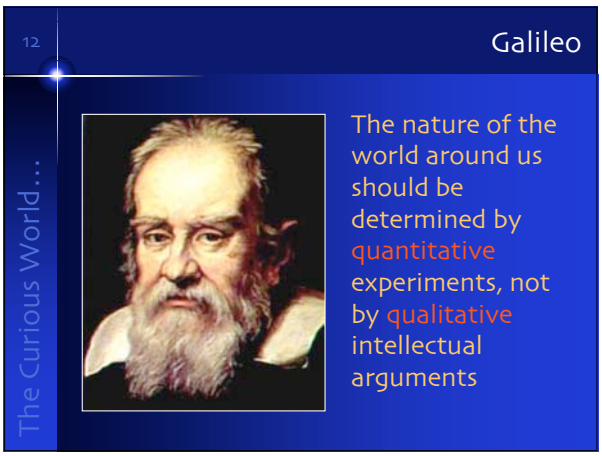
The Curious World of the Very Very Small



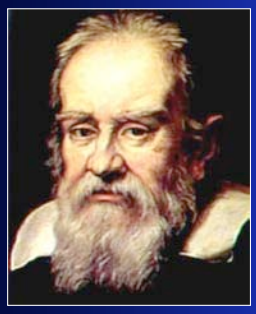








13 Galileo



Ask not

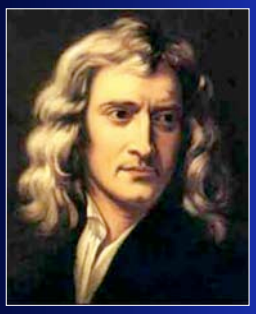
"What should happen if…?"

but

"What actually happens if…?"

The Curious World…

14 Newton



Laws of Motion

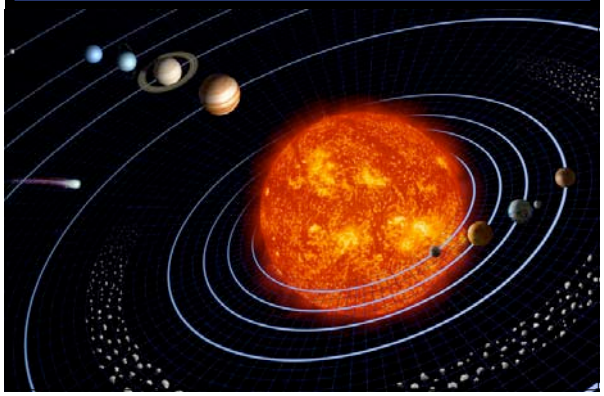
Law of Gravity

Nature of Light

"Classical Mechanics"

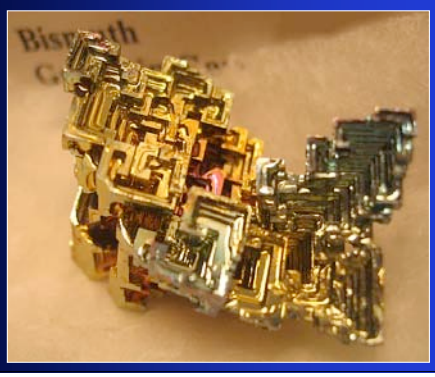
The Curious World…

'Clockwork' Universe



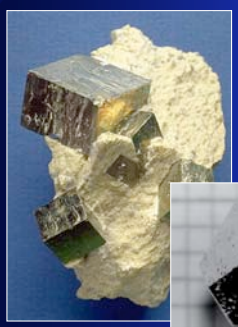
Snowflakes

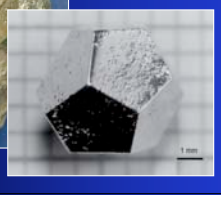
17 Structure Within



The Curious World…

18 Structure Within

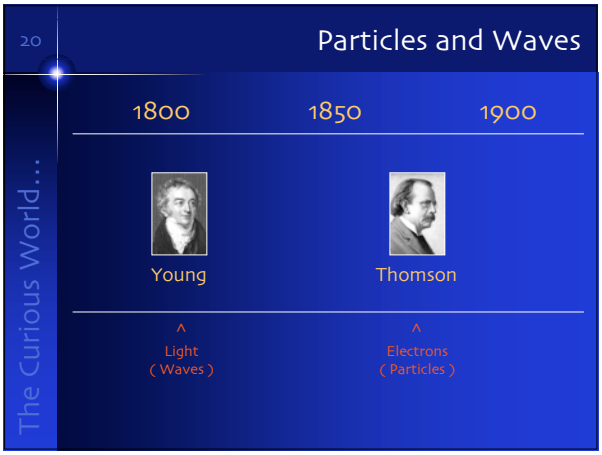


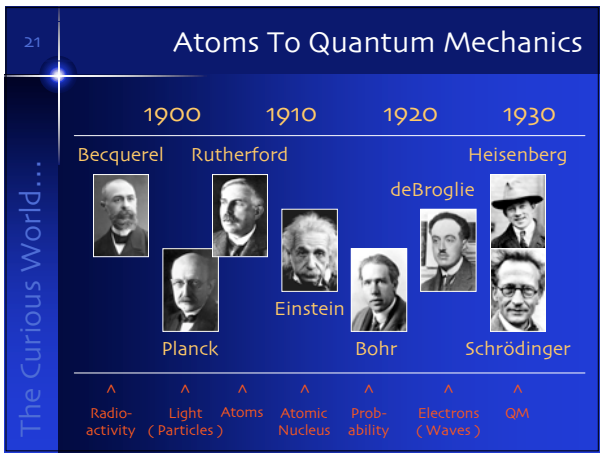


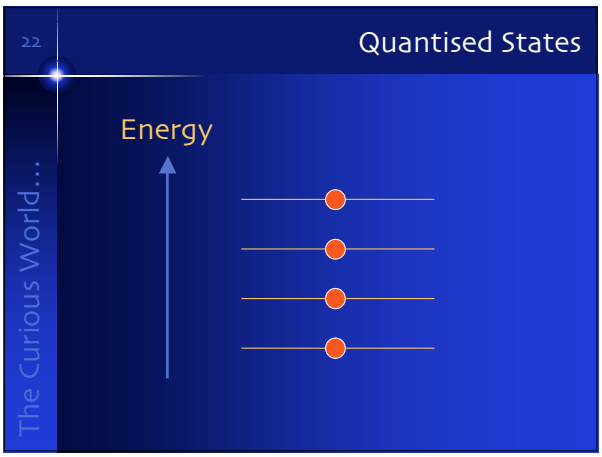
The macroscopic shape and symmetry of crystals must be telling us something about underlying structure

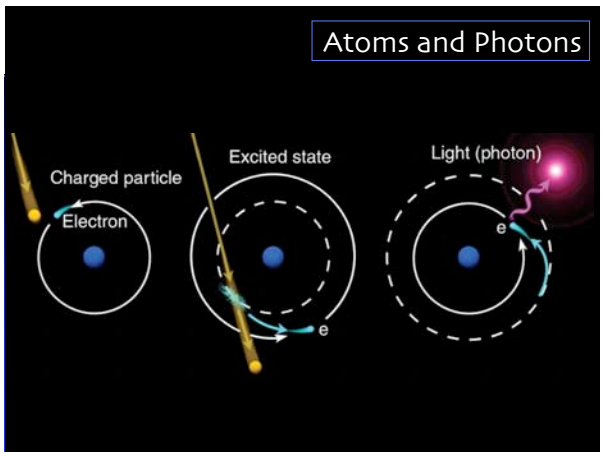
The Curious World…

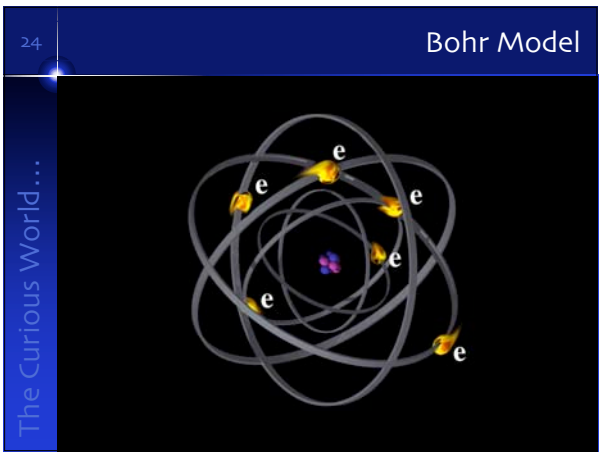
The Curious World of the Very Very Small



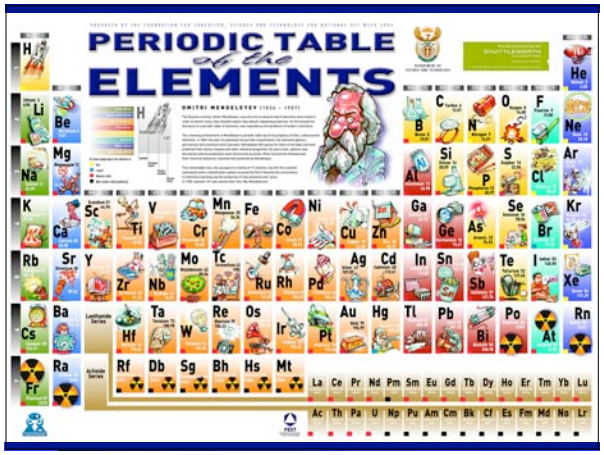


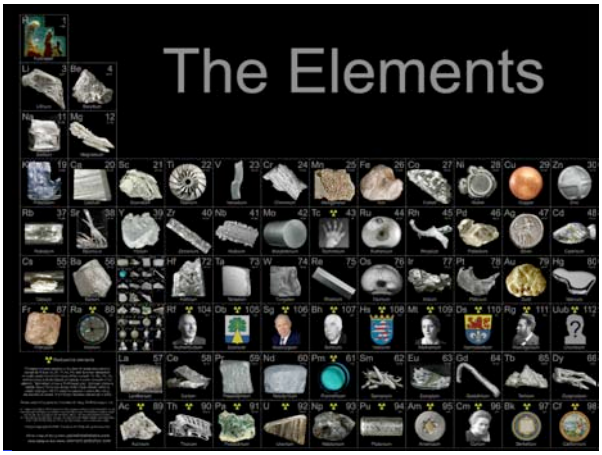


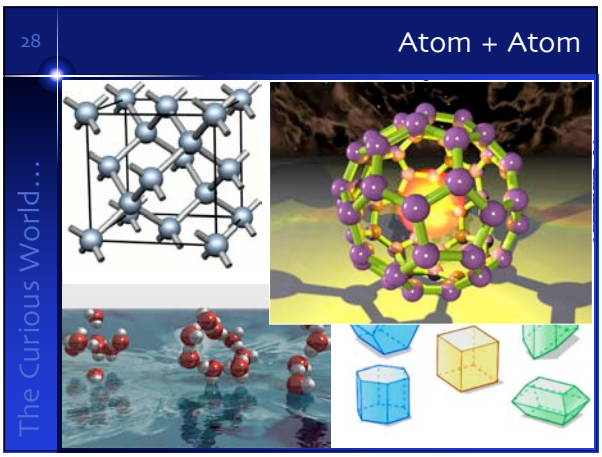


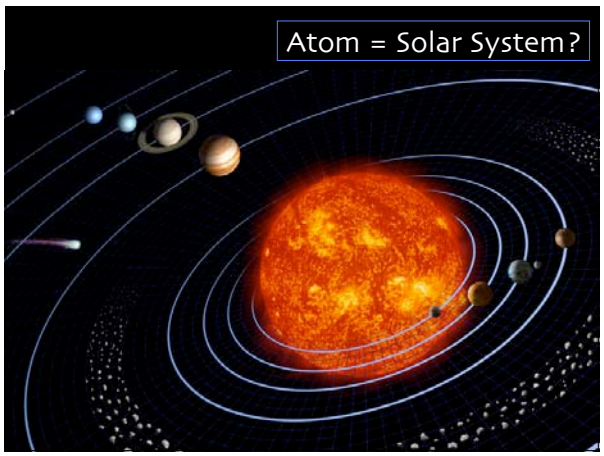


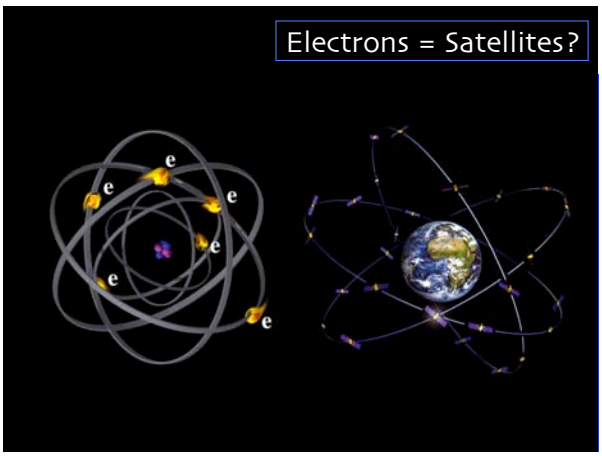
The Curious World of the Very Very Small



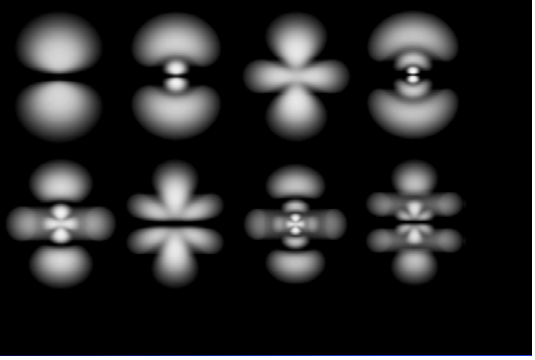








Electrons = Clouds?



32 Dealing With Atoms

The Curious World…

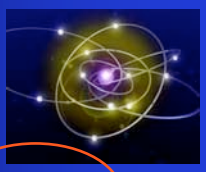
Particles
Waves
Orbits
Spin
Energy

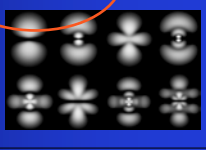
Words

Pictures

Maths

$H\psi = E\psi$





33 Heisenberg

The Curious World…

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

34 Dealing With Atoms

The Curious World…

Would it be better to use words that don't carry any 'baggage', or preconceptions?

Rather than say…

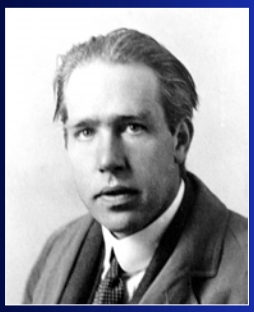
"The electrons orbit and spin in the atom"

Would it be better to say…

"The slithy toves did gyre and gimbal in the wabe"

35 Bohr

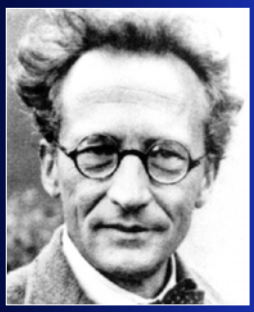
The Curious World…



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

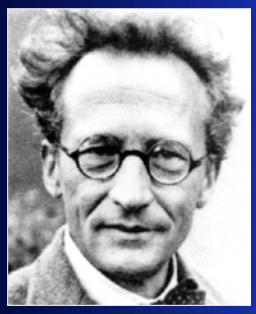
36 Schrödinger

The Curious World…



"Atomic physics has shown that atoms have no meaning, but can only be understood in experimental measurement"

37 Schrödinger



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

38 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, …

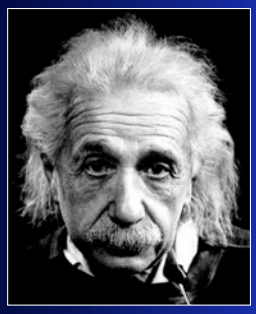
Atoms do not have a finite size

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

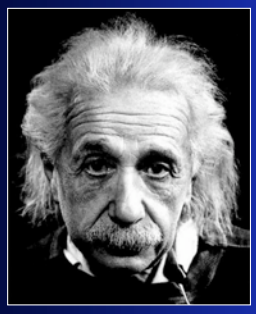
39 Einstein



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

40 Heads or Tails?

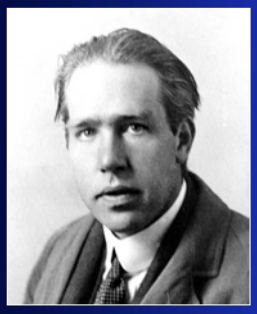
41 Einstein



"God does not play dice"

"God is subtle but he is not malicious"

42 Bohr



"Stop telling God what to do!"

43 Three Aspects of QM

The Curious World…

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

44 Order Matters

The Curious World…

In algebra

$$A \times B = B \times A$$

In Quantum Mechanics

$$A \times B \neq B \times A$$

So what?

45 If Order Matters

The Curious World…

Top pair : carnivores

Bottom pair : veggies

Left pair : 4 legs

Right pair : wings

46 If Order Matters

The Curious World…

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!

47 If Order Matters

The Curious World…

If we had picked in a different order…

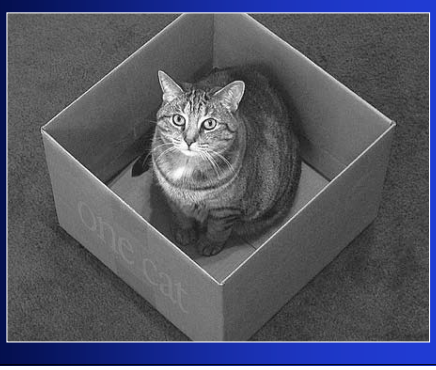
First pick the **4-legged** animals

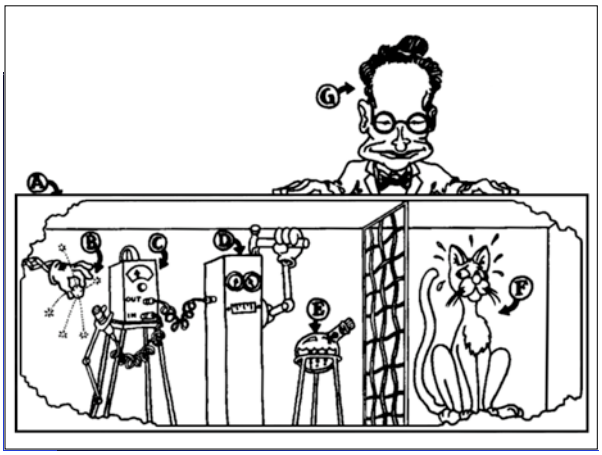
Then pick the **veggie** animals

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

48 Schrödinger's Cat

The Curious World…





50 Schrödinger's Cat

The Curious World…

51 QM and Dogs

The Curious World…

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

52 How Do We Know QM Is Right?

The Curious World…

So far, nothing has proved it wrong

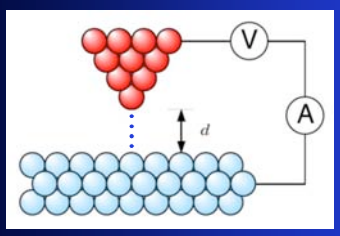
Quantum Mechanics predicts results that are impossible by 'Classical Mechanics'

Using QM theory, we can build a microscope that can 'see' atoms

53 Scanning Tunnelling Microscope

The Curious World…

Sharp tip



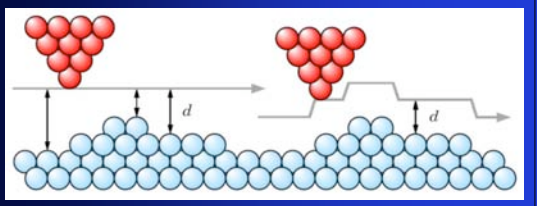
Current flows

Sample

54 STM

The Curious World…

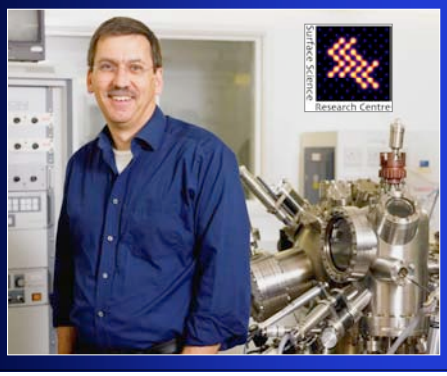
Move tip across sample…



…measuring current at each point

The Curious World of the Very Very Small

55 Surface Science



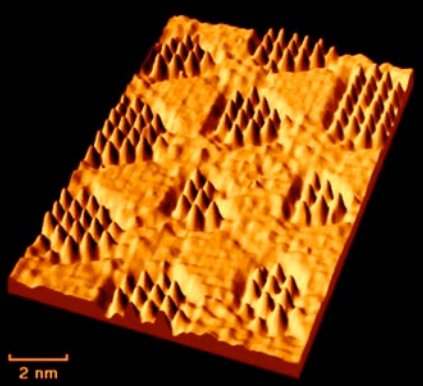
The Curious World…

56 Surface Science

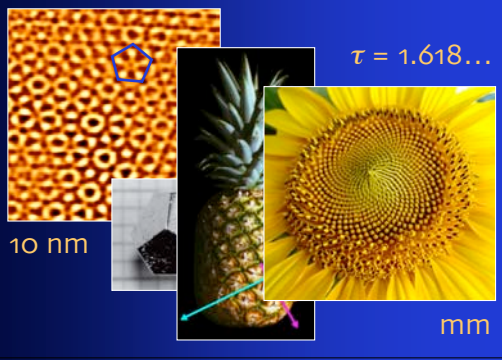
The STM is sealed inside an ultra-high vacuum vessel (10^{-13} atms) to keep it and the sample surface clean.

The Curious World…

STM

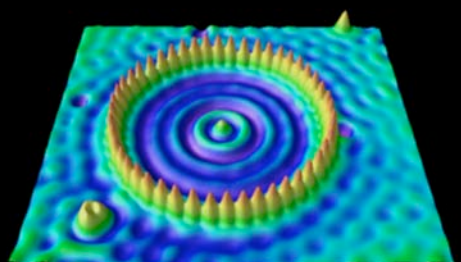


58 Patterns — Small and Large



The Curious World…

59 STM of Atomic Corral



The Curious World…

60 And Beyond…

As far as we know…

Electrons are fundamental particles

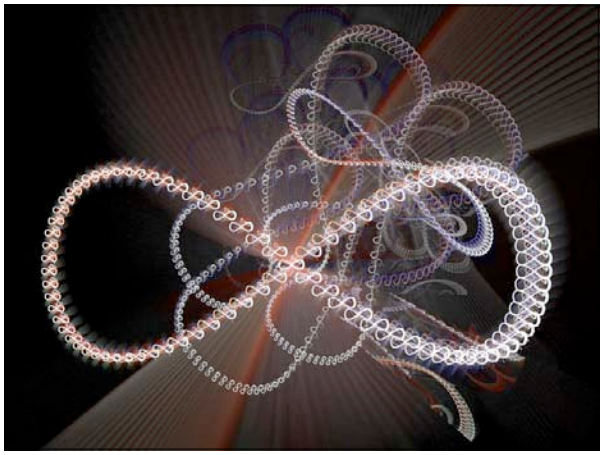
Atomic nuclei are made of

Protons and Neutrons (~fm)

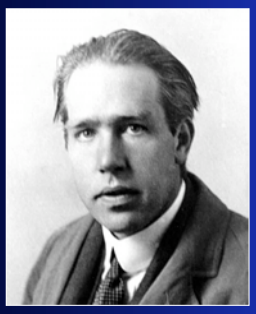
…which are made of Quarks

…which are made of… ?

The Curious World…



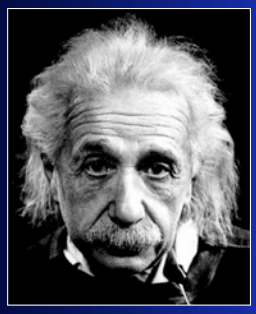
62 Bohr



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

The Curious World...

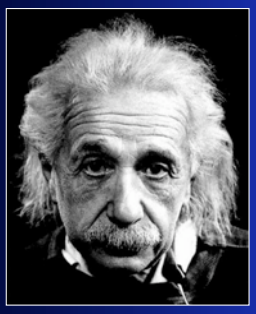
63 Einstein



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

The Curious World...

64 Einstein



"The most beautiful thing we can experience is the mysterious. He who can no longer pause to wonder and stand rapt in awe, is as good as dead"

The Curious World...

65 The Curious World...

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.

William Blake

The Curious World...

The Curious World of the Very Very Small

Dr Steve Barrett Jan 2008