


The Weird World of the Very Very Small

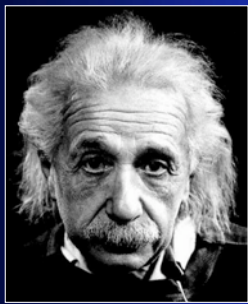
**The Weird World
of the
Very
Very
Small**



Dr Steve Barrett Feb 2008

2 Introduction

The Weird World...



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

3 Introduction

The Weird World...

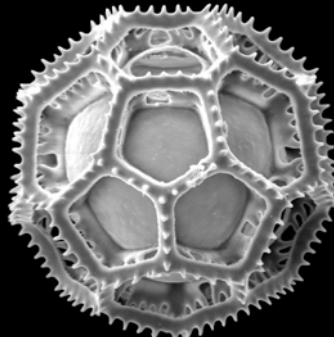
A Sense of Scale
Metres → Nanometres

A Sense of Symmetry
Underlying Structure

The Quantum World
Seeing Atoms

And Beyond...
What is Even Smaller?

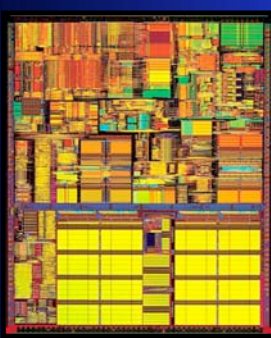
A Sense of Scale



$\frac{1}{20}$ mm
= 50 μ m

5 A Sense of Scale

The Weird World...



Microprocessor chip area
~ mm² ...

10 million transistors...

so size of components
~ 10-100 nm

6 Structure Within

The Weird World...

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

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7 Aristotle

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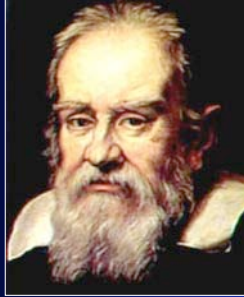


Elements

- Fire
- Air
- Water
- Earth

8 Galileo

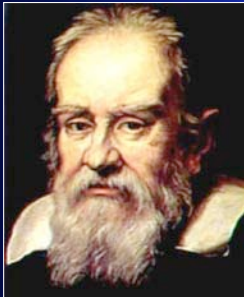
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The nature of the world around us should be determined by **quantitative** experiments, not by **qualitative** intellectual arguments

9 Galileo


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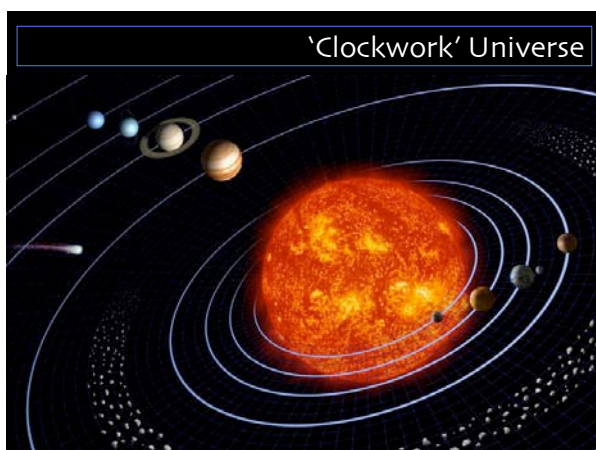
Ask not
"What **should** happen if...?"
but
"What **actually** happens if...?"

10 Newton

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

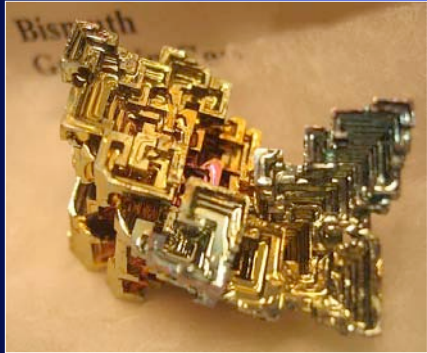


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Structure Within

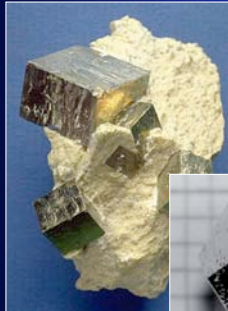
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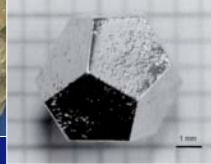
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Structure Within

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



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Atoms



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1600	1700	1800	1900
Democritus	Boyle	Dalton	Maxwell
			
	Newton		
			
	Lavoisier	Avogadro	Boltzmann
			

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Particles and Waves









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1800	1850	1900
Young		Thomson
		
Light (Waves)		Electrons (Particles)

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Atoms To Quantum Mechanics

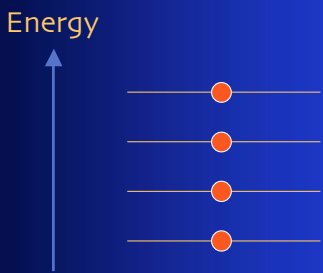
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1900	1910	1920	1930
Becquerel	Rutherford	deBroglie	Heisenberg
			
Planck	Einstein	Bohr	Schrödinger
			
Radio-activity	Light (Particles)	Atoms	Atomic Nucleus
^	^	^	^
Probability	Electrons (Waves)	QM	

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Quantised States

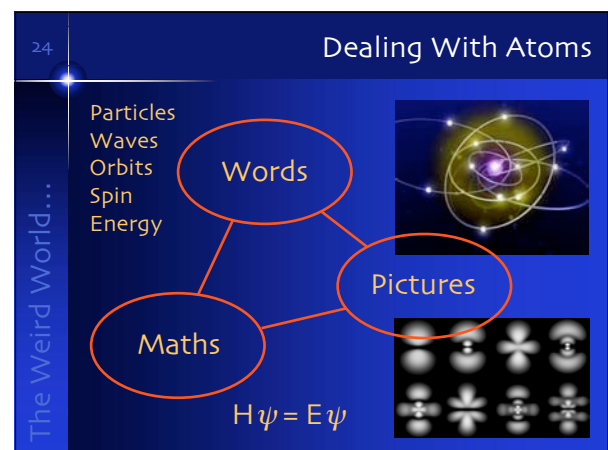
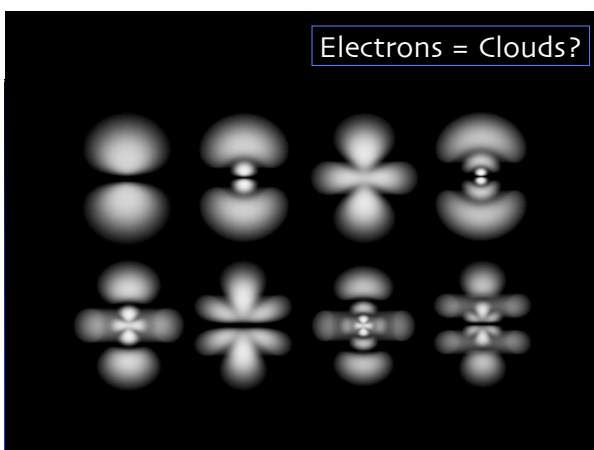
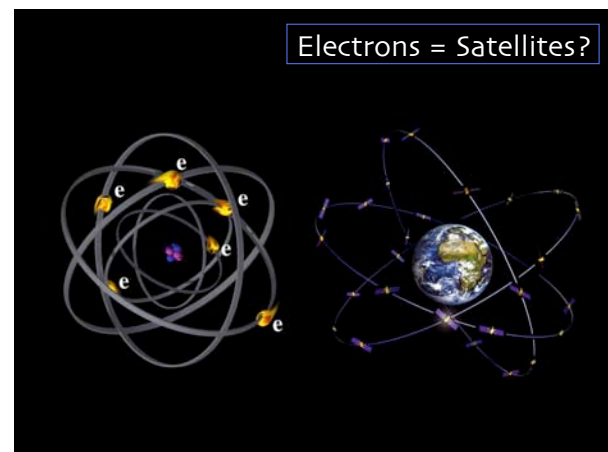
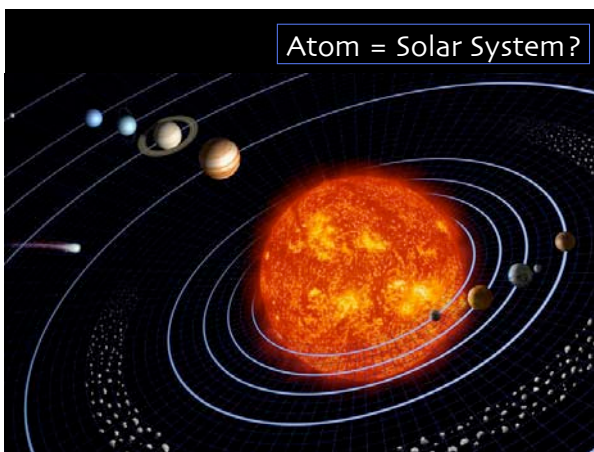
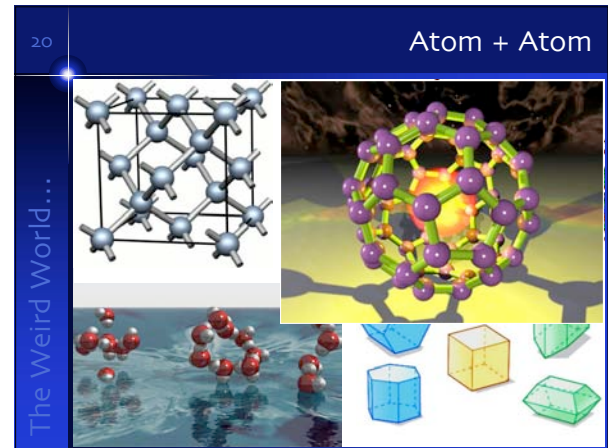
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PERIODIC TABLE of the ELEMENTS


DMITRI MENDELEEV (1869 - 1907)



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25 Heisenberg

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

26 Dealing With Atoms

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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"

27 Bohr

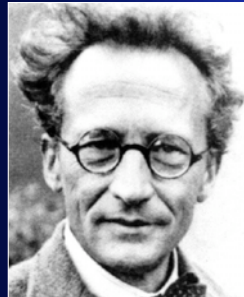
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"Everything we call real is made of things that cannot be regarded as real"

28 Schrödinger

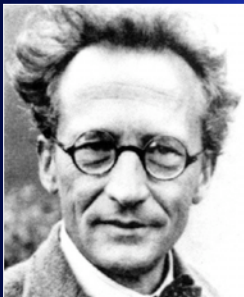
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"Atomic physics has shown that atoms have no meaning, but can only be understood in experimental measurement"

29 Schrödinger

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

30 QM vs Common Sense

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

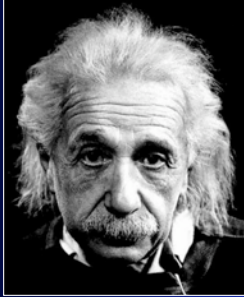
Atoms do not have a finite size
Electron 'in' an atom could be **anywhere**

Atoms can be in two states at the same time
Electron 'spin' can be simultaneously clockwise and anticlockwise

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31 Einstein


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

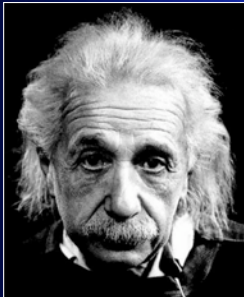
32 Heads or Tails?

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33 Einstein

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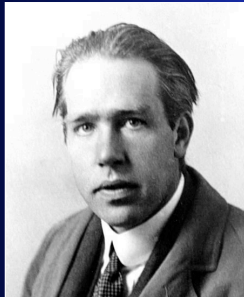


"God does not play dice"

"God is subtle but he is not malicious"

34 Bohr

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"Stop telling God what to do!"

35 Three Aspects of QM

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

36 Order Matters

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In algebra

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

In Quantum Mechanics

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

So what?

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37 If Order Matters

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Top pair : carnivores
Bottom pair : veggies

Left pair : 4 legs
Right pair : wings

38 If Order Matters


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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!

39 If Order Matters

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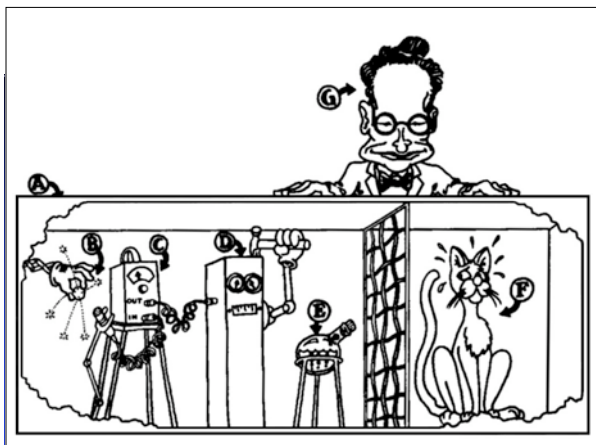


If we had picked in a different order...

First pick the **4-legged** animals
Then pick the **veggie** animals
You're left with waterbuck **and** roller!

40 Schrödinger's Cat

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42 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'

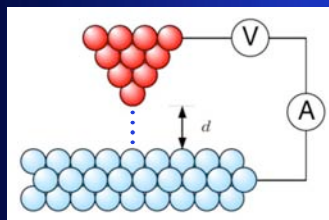
Using QM theory, we can build a microscope that can 'see' atoms

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Scanning Tunnelling Microscope

Sharp tip



Current flows

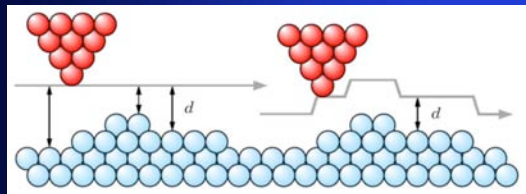
Sample

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STM

Move tip across sample...

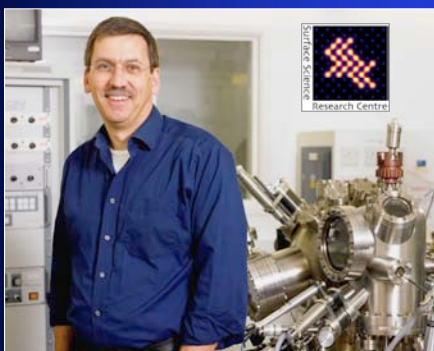


...measuring current at each point

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Surface Science



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Surface Science



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

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