OUR QUANTUM WORLD
Wave Particle duality of Nature

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OUTLINE

Atom and its size

Waves and Particles

Waves as particles and Particles as Waves – Quantum View

Milestones of Quantum physics

Wave nature of Matter : de Broglie

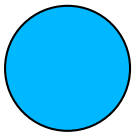
Interference of waves

Heisenberg's uncertainty principle

Quantum versus Classical world view

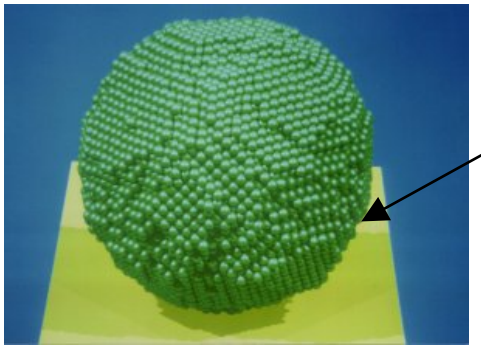
How big are atoms ?

Democritus : Atoms as building blocks.



Size?
Shape ?
Substance?

17000 Copper atoms



Diameter 10^{-7} cm

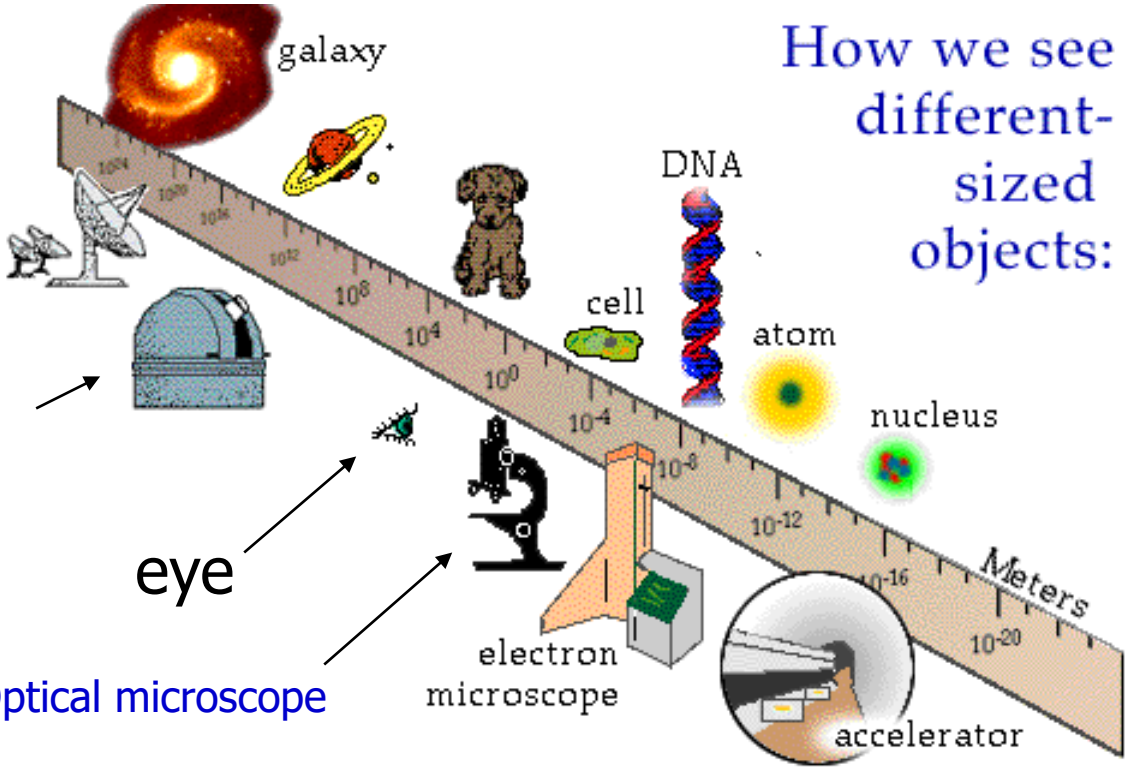
1 nm = 10^{-9} meters

Atomic size determined not till the 19th century

Atoms are very small ; about 0.5 nanometers.

Nanotechnology deals with atomic manipulations.

Objects



VLA Radio Tel

KECK Tel

eye

Optical microscope

Techniques of observation

T

http://www.vendian.org/howbig/

Helps you visualize sizes

Waves and Particles : What do we mean by them?

Material Objects:

Ball, Car, person, or point like objects called particles.

They can be located at a space point at a given time.

They can be at rest, moving or accelerating.

Falling Ball

Ground level

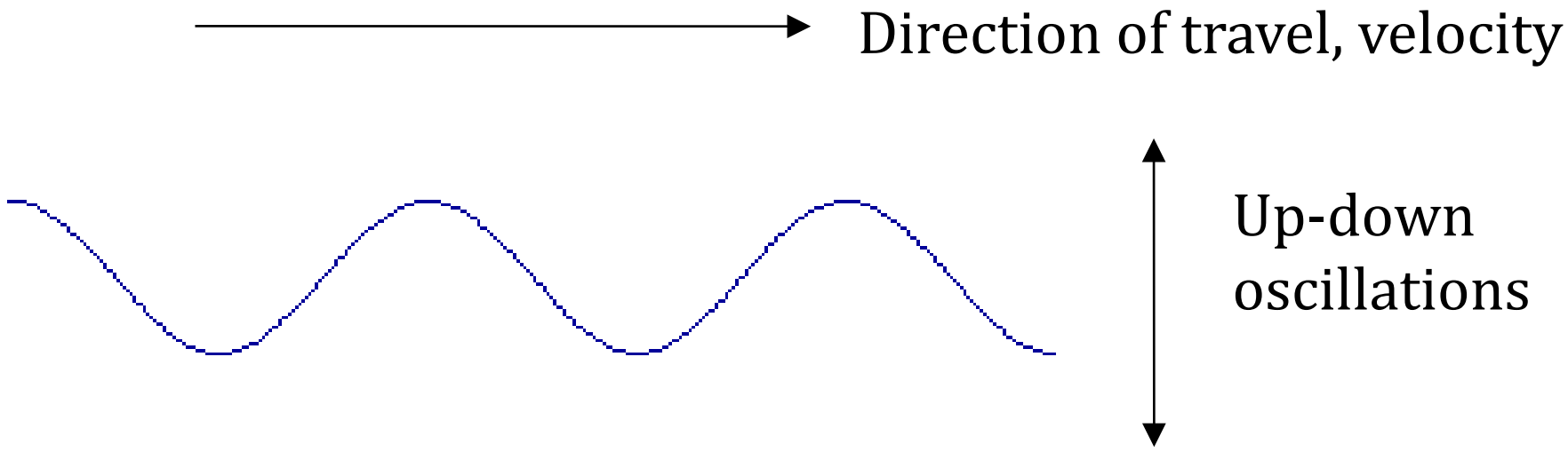
Waves and Particles: What do we mean by them ?

Common types of waves:

Ripples, surf, ocean waves, sound waves, radio waves.

Need to see crests and troughs to define them.

Waves are oscillations in space and time.

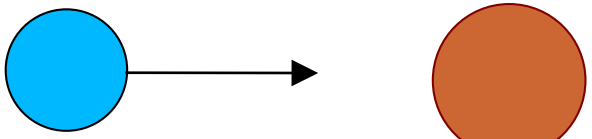


Wavelength ,frequency, velocity and oscillation size defines waves

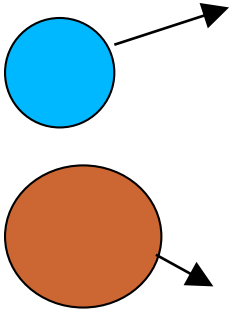
Particles and Waves: Basic difference in behaviour

When particles collide they cannot pass through each other !
They can bounce or they can shatter

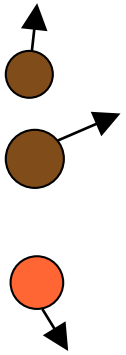
Before collision

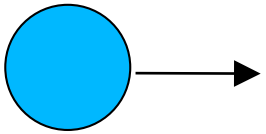


After collision



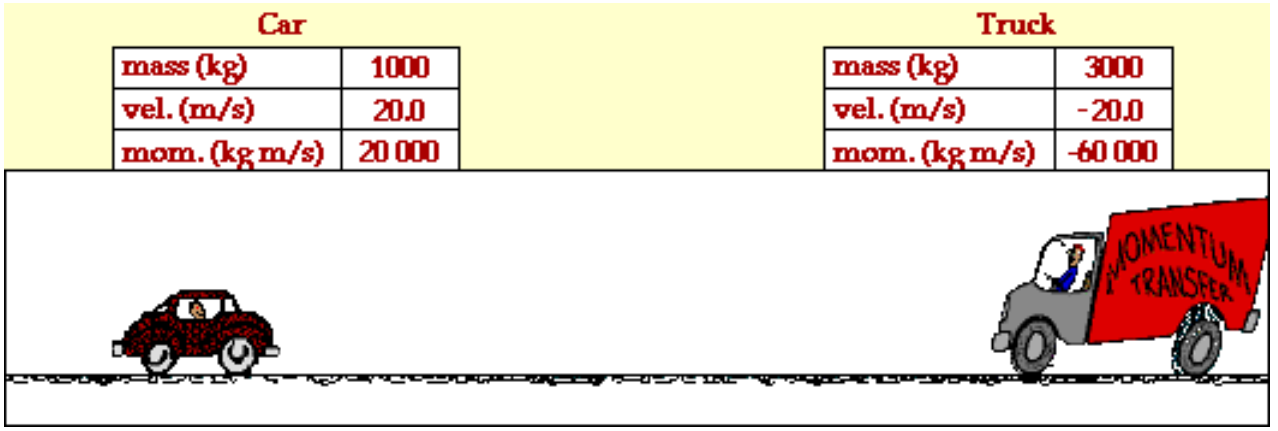
Another after collision state shatter





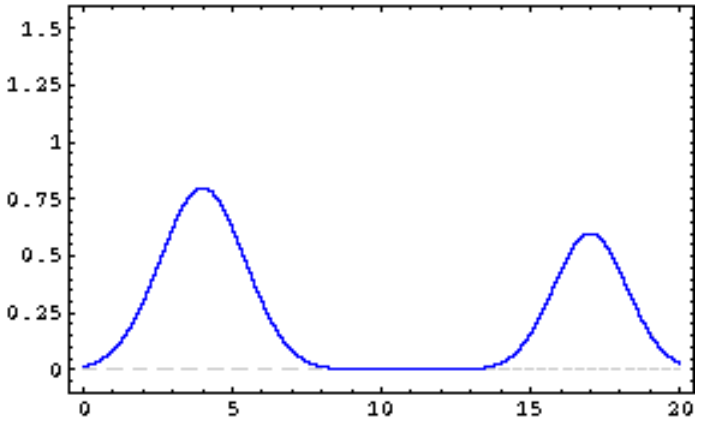
Collision of truck with ladder on top with a Car at rest ! Note the ladder continue its Motion forward ….. Also the small care front End gets smashed.

Head on collision of a car and truck
Collision is inelastic – the small car is dragged along
By the truck……

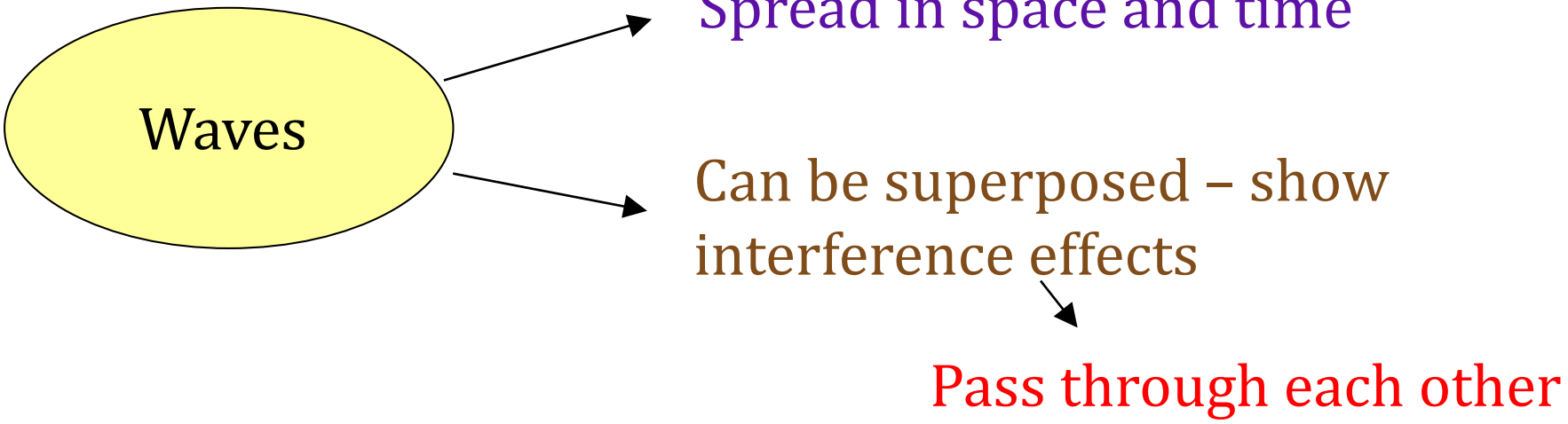


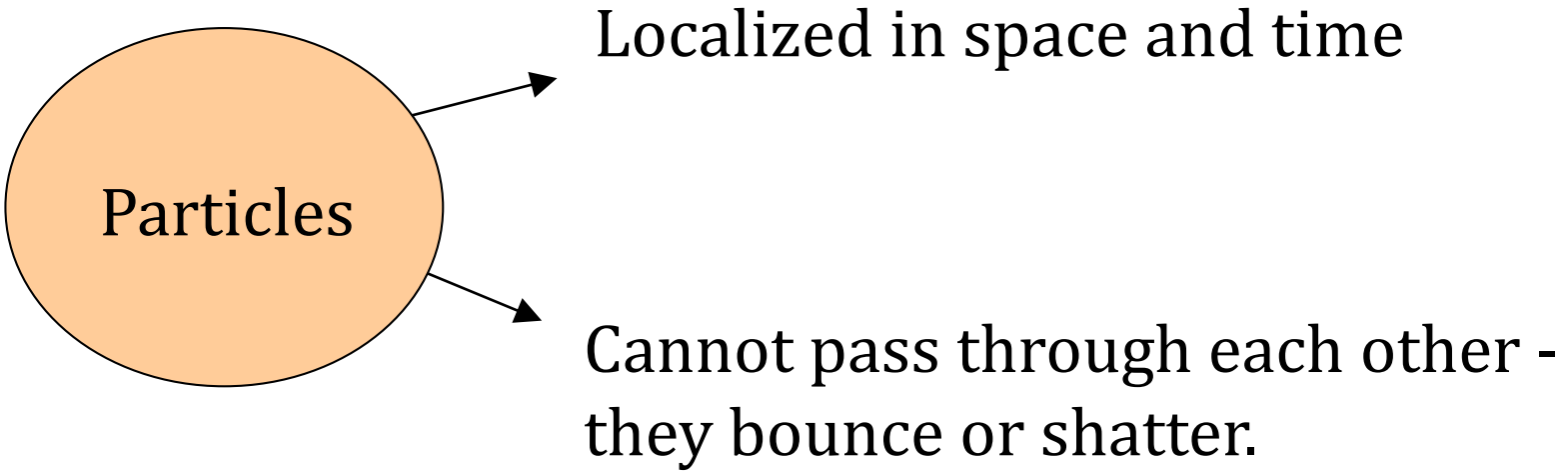
Waves and Particles Basic difference:

- Waves can pass through each other !
- As they pass through each other they can enhance or cancel each other
- Later they regain their original form !



Waves and Particles:





OUR QUANTUM WORLD

In the 20th century, study of atomic systems required a fundamental revision of these classical ideas about physical objects.

1. Light waves exhibited particle like properties – phenomena called photo-electric effect in which light impinging on certain metals cause instanteous emission of electrons in a billiard ball like impact.
– the basis of automatic door openers in grocery stores

2. Electrons (particles) exhibit wave like properties – they can pass through each other ! Phenomenon of electron interference – basis of electron microscopes

OUR QUANTUM WORLD

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This quantum picture of the world is at odds with our common sense view of physical objects. We cannot uniquely define what is a particle and what is a wave !!

Neils Bohr and Werner Heisenberg were the architects of this quantum world view, along with Planck, Einstein, de Broglie, Schrodinger, Pauli and Dirac.

TRUE UNDERSTANDING OF NATURE REQUIRED

THAT PHYSICAL OBJECTS, WHATEVER THEY ARE, ARE NEITHER EXCLUSIVELY PARTICLES OR WAVES

No experiment can ever measure both aspects at the same time, so we never see a mixture of particle and wave.

WHEN ONE OBSERVES A PHYSICAL PHENOMENON INVOLVING A PHYSICAL OBJECT, THE BEHAVIOUR YOU WILL OBSERVE – WHETHER PARTICLE LIKE OR WAVE LIKE – DEPENDS ON YOUR METHOD OF OBSERVATION.

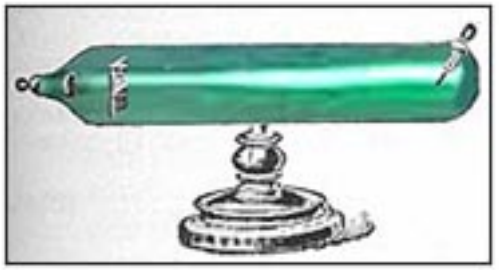
THE OBJECT IS DESCRIBED BY MATHEMATICAL FUNCT IONS WHICH ARE MEASURES OF PROBABILITY .

MILESTONES OF QUANTUM PHYSICS:


THOMSON

J.J.Thomson Established electron as a fundamental particle of nature. He measured its charge to mass ratio using a Crooke's tube.

Electric current = flow of electrons



Crooke's tube: Evacuated tube Visualization of electron beam.

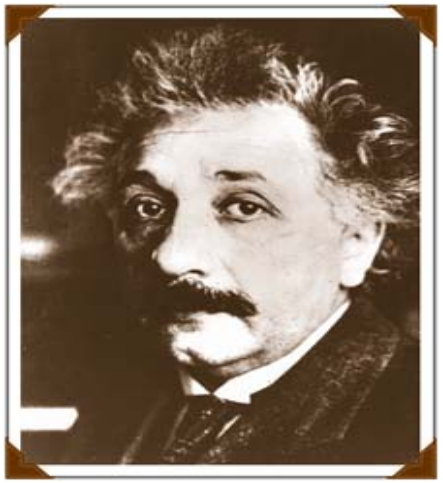
Animation of electrons moving and being deflected by an electric or magnetic field.

Marie Curie and Radioactivity - 1898

Discovered that certain elements ' spontaneously ' emit radiations and change into different elements.

Only woman scientist to receive two Nobel Prizes: One in chemistry and the other in physics.

The Quantum of Light or the Photon



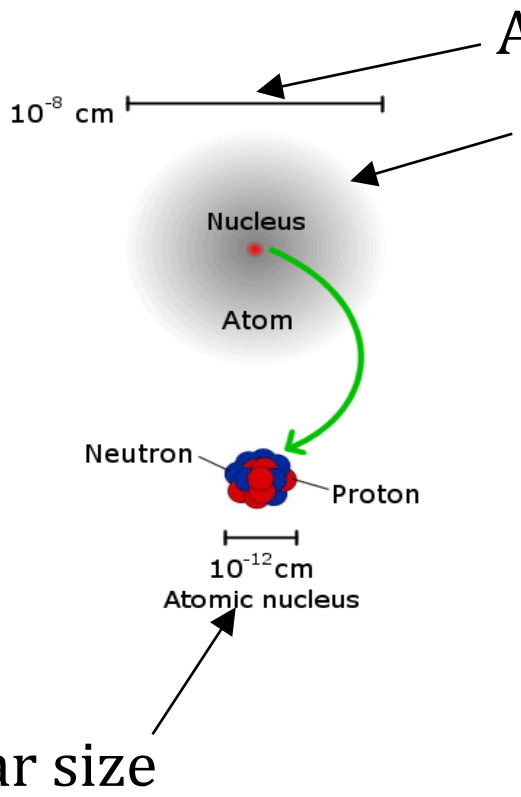
Particle nature of light was proposed by Einstein in 1905 to explain the photo-electric effect. Photo-electric effect – automatic door openers in grocery stores. Particles of light are called light quanta or photons.

Energy of a Photon = h (frequency of light)
h is a fundamental constant of nature and it is very small in size.

Packet of energy in photon is so small that we are not aware of the rain of photons of light impinging on our eyes – just as you cannot feel the impact of individual air molecules, you only feel a breeze.

Rutherford and his Nuclear Atom: 1898 -1911

Ernest Rutherford used alpha rays to discover the nucleus of the atom. The nucleus was positvely charged and contained almost all of the mass of the atom. Most of the atom was empty space.



Classical physics required that this atom is unstable electrons would fall into the nucleus in 10^{-7} sec!

Planck and quantization of atomic " vibrations "

Before Einstein, Planck postulated from study of radiation from hot bodies that the radiating atoms can only radiate energy in discrete amounts – or that atoms exist only in discrete states, called Quantum states.

This was the birth of quantum physics in 1900

THE BOHR ATOM:


BOHR

Bohr proposed a revolutionary model: An atom with discrete (Quantum) states – an ad hoc model

Bohr model explained how atoms emit light quanta and their stability. He combined the postulates of Planck and Einstein to build characteristic energy states that atoms should possess. Model gave excellent agreement with experiment on atomic spectra.(1913)

Bohr atom

Bohr's atom model achieved three important results:

1. Atoms are stable
2. Different atoms of the same element are identical
3. Atoms regenerate if they are taken apart and then allowed to reform.

THE BOHR ATOM:

BOHR

Understanding the origin of Bohr's model required an essential bold step – enter Louis de Broglie.

Wave nature of material bodies:

If light, which classically is a wave,
can have particle nature
As shown by Planck and Einstein,

Can material particles exhibit wave nature ?

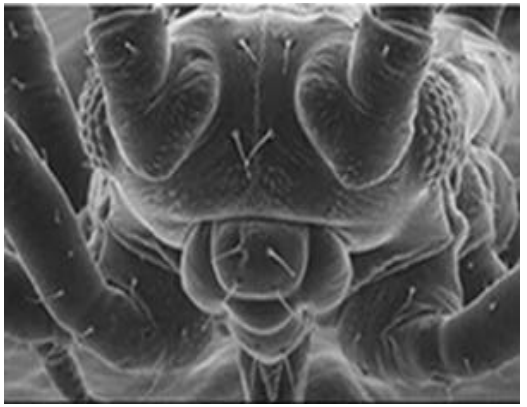
Prince Louis de Broglie while doing
his Ph.D. research said particles
should have wave like properties.

Wave Nature of Matter

Louis de Broglie in 1923 proposed that matter particles should exhibit wave properties just as light waves exhibited particle properties. These waves have very small wavelengths in most situations so that their presence was difficult to observe

These waves were observed a few years later by Davisson and G.P. Thomson with high energy electrons. These electrons show the same pattern when scattered from crystals as X-rays of similar wave lengths.

Electron microscope picture of a fly →



A SUMMARY OF DUAL ITY OF NATURE

Wave particle duality of physical objects

LIGHT

Wave nature -EM wave

Optical microscope

Interference

Particle nature -photons

Convert light to electric current

Photo-electric effect

PARTICLES

Wave nature

Matter waves -electron microscope

Discrete (Quantum) states of confined systems, such as atoms.

Particle nature

Electric current

photon-electron collisions

QUNATUM MECHANICS:

ALL PHYSICAL OBJECTS exhibit both PARTICLE AND WAVE LIKE PROPERTIES. THIS WAS THE STARTING POINT OF QUANTUM MECHANICS DEVELOPED INDEPENDENTLY BY WERNER HEISENBERG AND ERWIN SCHRODINGER.

Particle properties of waves: Einstein relation:
Energy of photon = h (frequency of wave).

Wave properties of particles: de Broglie relation:
wave length = h/(mass times velocity)

Physical object described by a mathematical function called the wave function.

Experiments measure the Probability of observing the object.

A localized wave or wave packet:

A moving particle in quantum theory

Spread in position

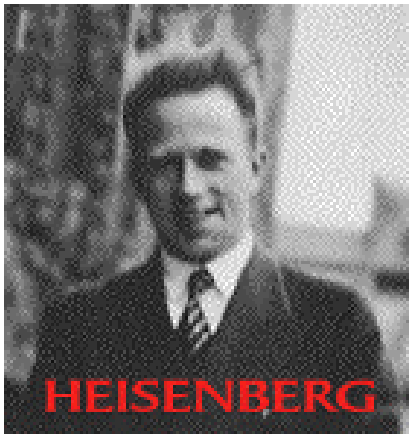
Spread in momentum

Superposition of waves
of different wavelengths
to make a packet

Narrower the packet , more the spread in momentum

Basis of Uncertainty Principle

ILLUSTRATION OF MEASUREMENT OF ELECTRON POSITION



Act of measurement
influences the electron
-gives it a kick and it
is no longer where it
was ! Essence of uncertainty
principle.

Classical world is Deterministic:

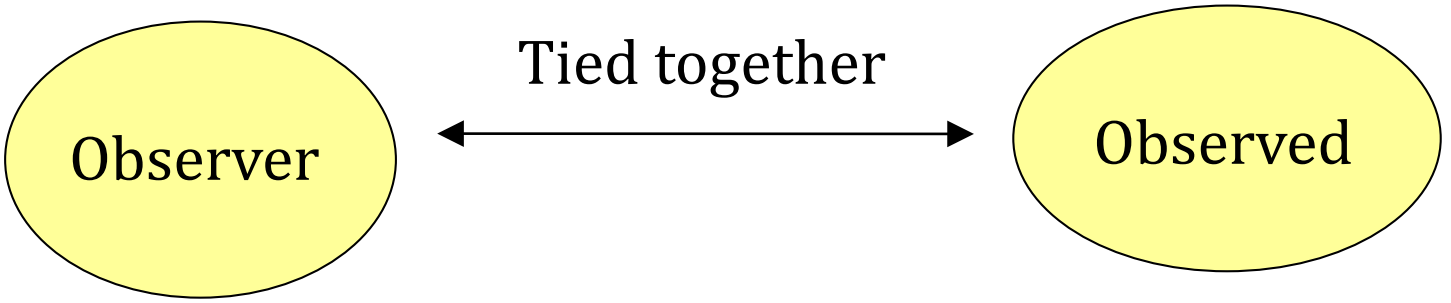
Knowing the position and velocity of all objects at a particular time

Future can be predicted using known laws of force and Newton's laws of motion.

Quantum World is Probabilistic:

Impossible to know position and velocity with certainty at a given time.

Only probability of future state can be predicted using known laws of force and equations of quantum mechanics.



BEFORE OBSERVATION IT IS IMPOSSIBLE TO SAY WHETHER AN OBJECT IS A WAVE OR A PARTICLE OR WHETHER IT EXISTS AT ALL !!

QUANTUM MECHANICS IS A PROBABILISTIC THEORY OF NATURE

UNCERTAINTY RELATIONS OF HEISENBERG ALLOW YOU TO GET AWAY WITH ANYTHING PROVIDED YOU DO IT FAST ENOUGH !! example: Bank employee withdrawing cash, using it ,but replacing it before he can be caught ...

CONFINED PHYSICAL SYSTEMS – AN ATOM – CAN ONLY EXIST IN CERTAIN ALLOWED STATES ... .

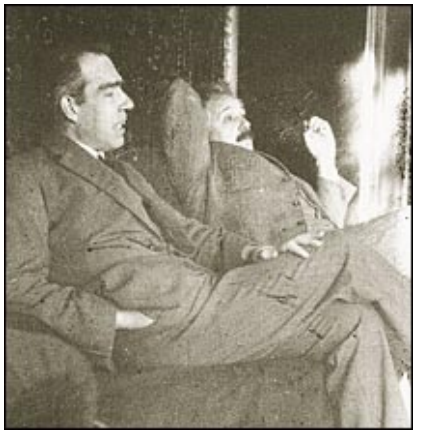
THEY ARE QUANTIZED

COMMON SENSE VIEW OF THE WORLD IS AN APPROXIMATION OF THE UNDERLYING BASIC QUANTUM DESCRIPTION OF OUR PHYSICAL WORLD !

IN THE COPENHAGEN INTERPRETATION OF BOHR AND HEISENBERG IT IS IMPOSSIBLE IN PRINCIPLE FOR OUR WORLD TO BE DETERMINISTIC !

EINSTEIN, A FOUNDER OF QM WAS UNCOMFORTABLE WITH THIS INTERPRETATION

God does not play dice !



Bohr and Einstein in discussion 1933