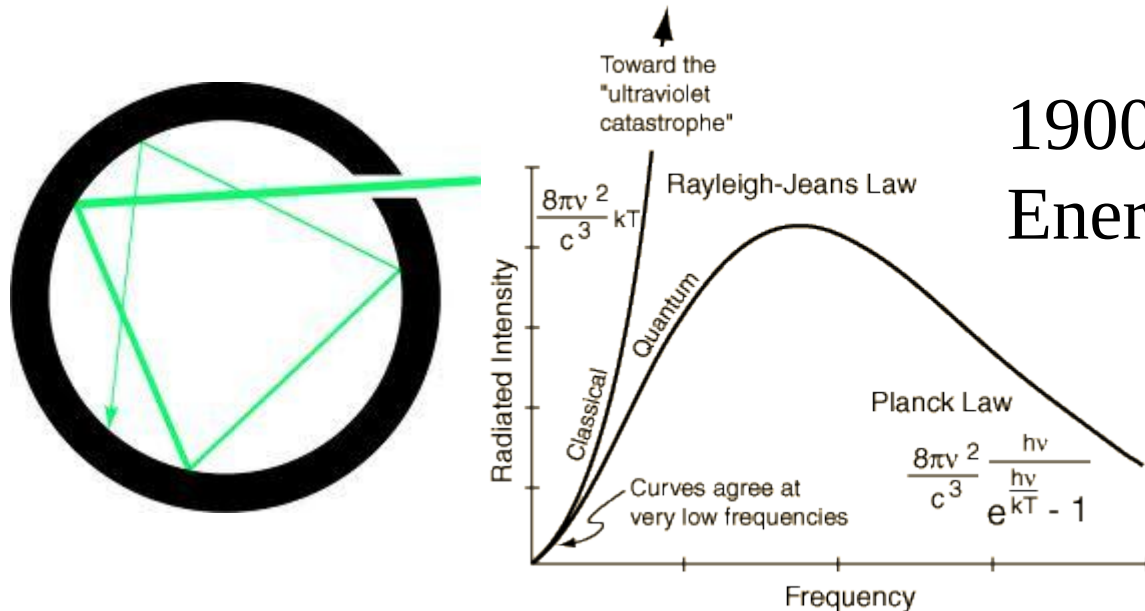


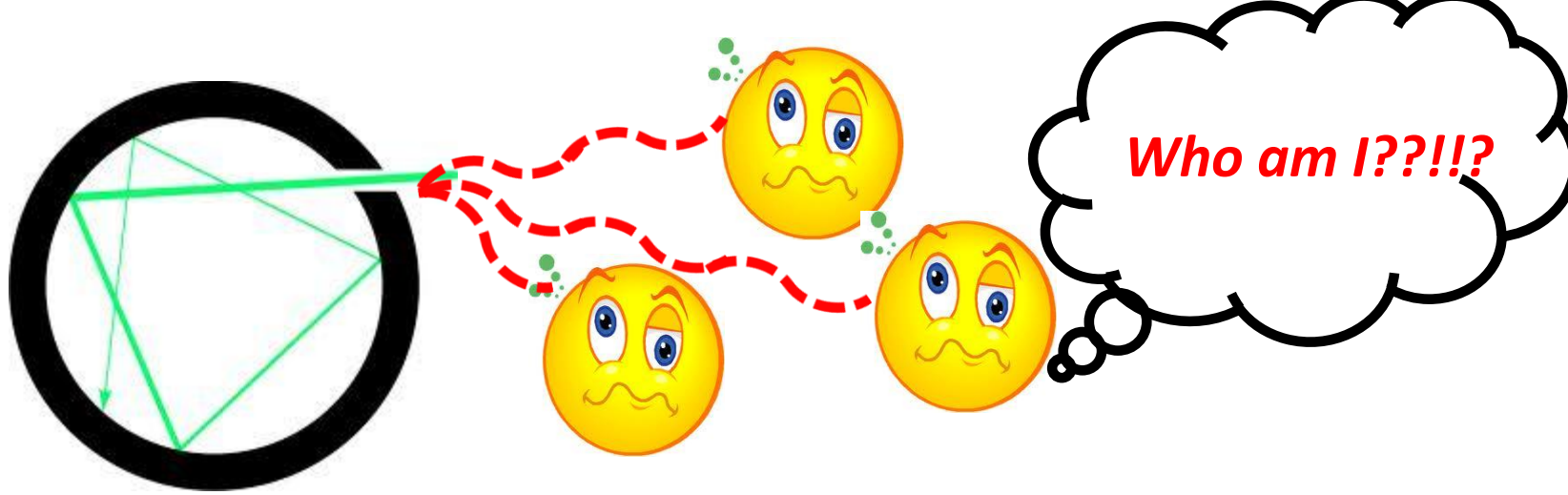
“Nature is made in such a way as to be able to be understood.... What we observe is not nature itself but nature exposed to our method of questioning.....”

~W. Heisenberg



1900:
Energy is emitted in quanta!!

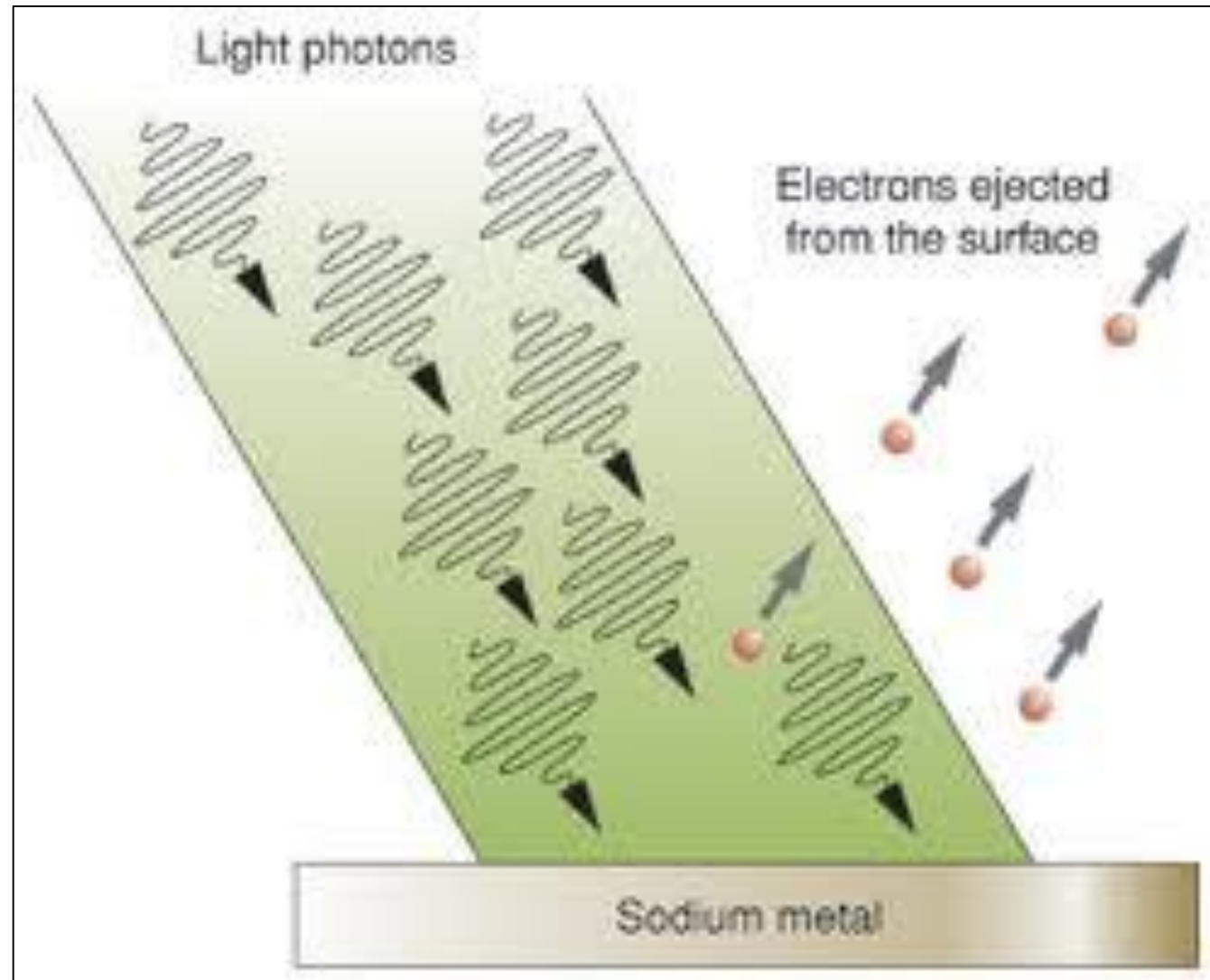
“an act of despair ... I was ready to sacrifice any of my previous convictions about physics.” ~ Max Planck



"a purely formal
assumption ... actually I did not think much about it..."
~ Max Planck

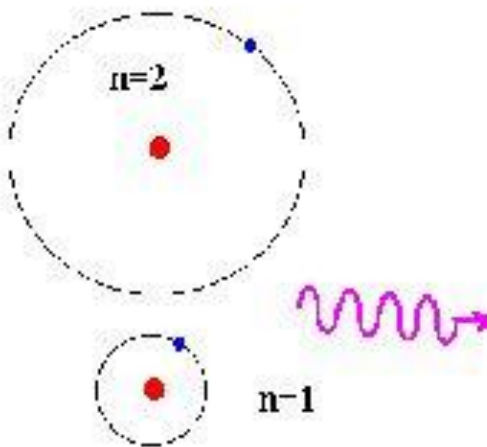
Energy is not only emitted, but propagates and absorbs in
Quanta... i.e. Energy behaves like a collection of particles..

Wave has a particle nature: Albert Einstein



1905:
Photoelectric effect

1913: Bohr's atomic model

Bohr Model of the Hydrogen Atom	
Electron orbits a proton in circular orbits. Angular momentum is quantized: $l = mvr = nh/2\pi$ h = Planck's constant Light emitted as photons $\Delta E = hf$	

Explained Hydrogen atom spectra

Birth of “*quantum*”

- Energy distribution of the blackbody radiation spectra:
 - Rayleigh Jeans formula $\Rightarrow$ low frequency limit $\Rightarrow$ ultraviolet catastrophe
 - Wien's formula $\Rightarrow$ high frequency limit: exponential dependence.
 - $\Rightarrow$ no physical understanding of the process... Only mathematical interpolation!
- Planck was desperate to give it some physical understanding.
- He tried to handle it with Maxwellian electrodynamics... And failed.
 - thus he took recourse to thermodynamics and tried to relate entropy with the radiated energy.
- From Wien's law of energy distribution, in high frequency limit, second differential coefficient of entropy $R \propto E$.
- In low frequency limit, experiments showed that $R \propto E^2$.
 - In order to interpret physically, Planck shifted to Boltzmann interpretation of entropy and second law of thermodynamics, where entropy is a measure of physical probability.
- Thus, R is a measure of probability of a particular energy distribution. In order to do this calculation of probability distribution, Planck stumbled upon two universal constants:
 - One- Boltzmann's constant and the other- *Quantum of action*!

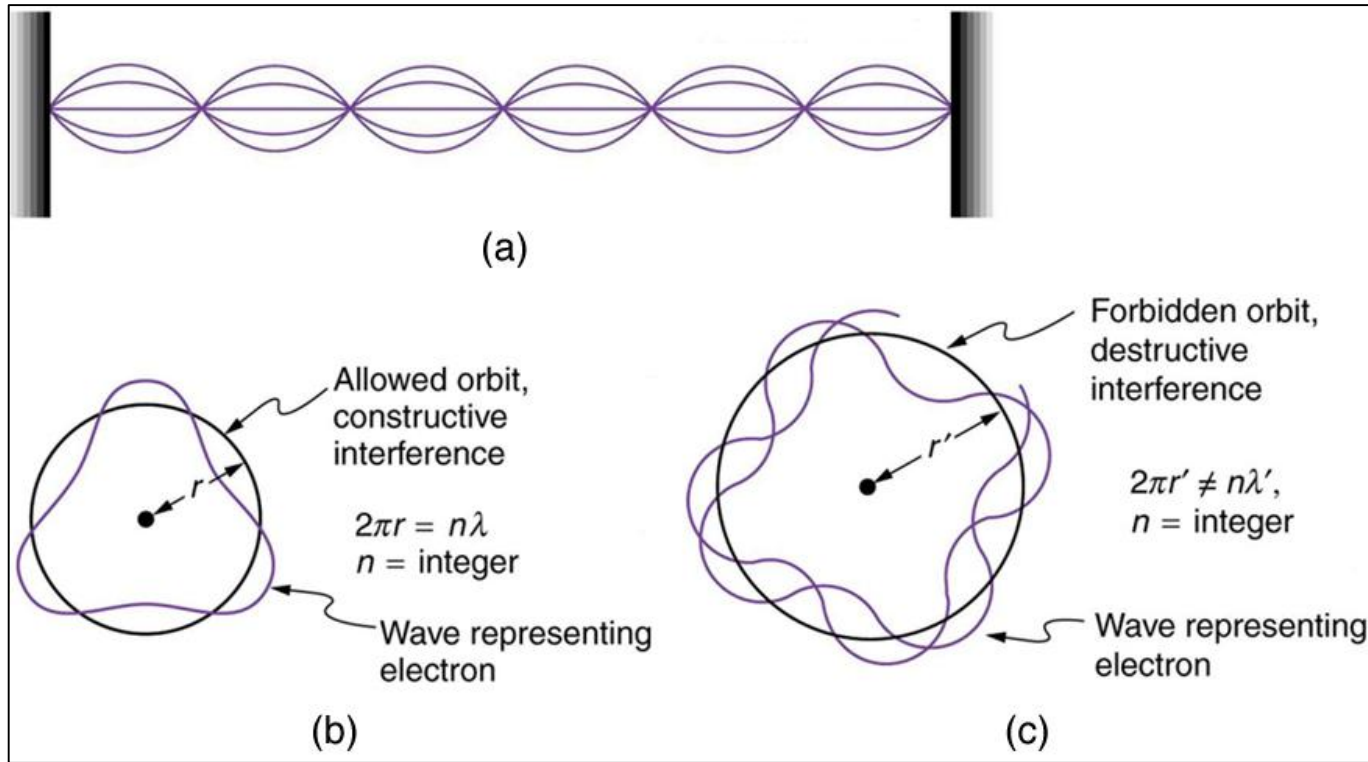
Planck tried helplessly to disprove this requirement of quantum...
Alas! This was the only choice if one wanted to fit
the experimental data with physics instead of mathematics!

The other side of the coin... 1927

“Determination of the stable motion of electrons in the atom introduces integers, and up to this point the only phenomena involving integers in physics were those of interference and of normal modes of vibration. This fact suggested to me the idea that electrons too could not be considered simply as particles, but that frequency (wave properties) must be assigned to them also.”

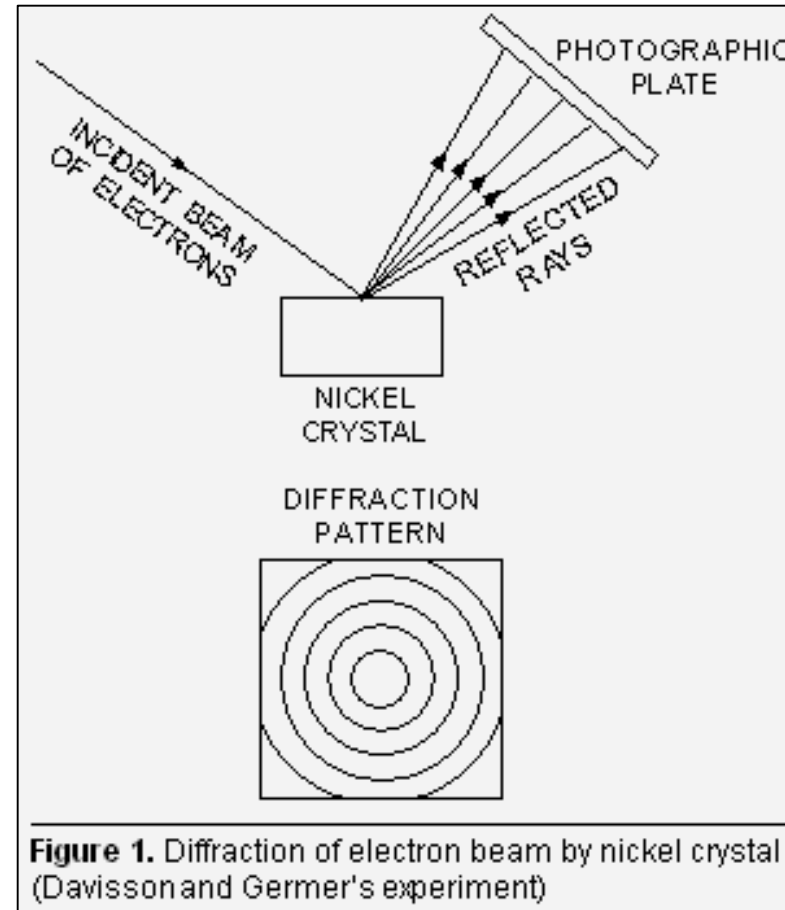
~Louis de Broglie, Nobel prize speech

Matter behaves as wave... Obeying “ $\lambda=h/p$ ”



Matter behaves as wave... Obeying “ $\lambda=h/p$ ”

Davisson Germer experiment, 1927



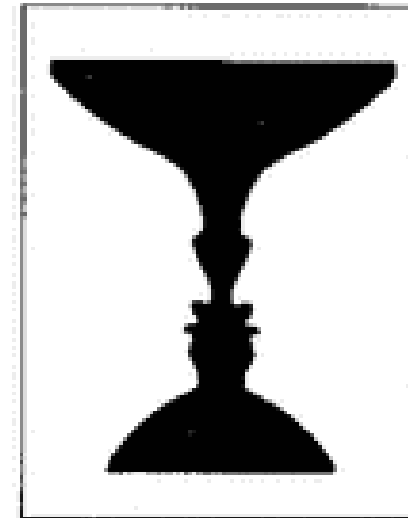
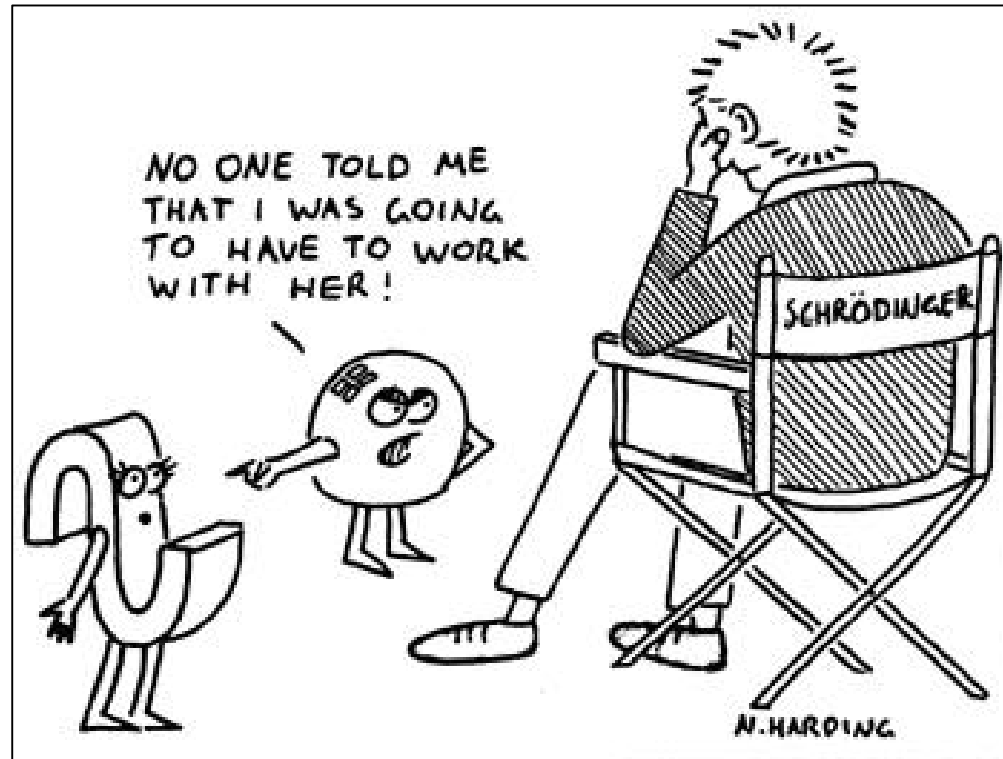
Wave-particle duality: Bohr's complementarity

What is light really?? Or what is electron really?? A particle? Or a wave?

It is like.... They can not exist as both. Sometimes they act as wave and sometimes they act as particles... Both nature cannot be manifest at the same time, yet electron or light is both at the same time! We have two contradictory pictures of reality at the same time. Neither of them fully explains nature while being single, but together: **they do**.

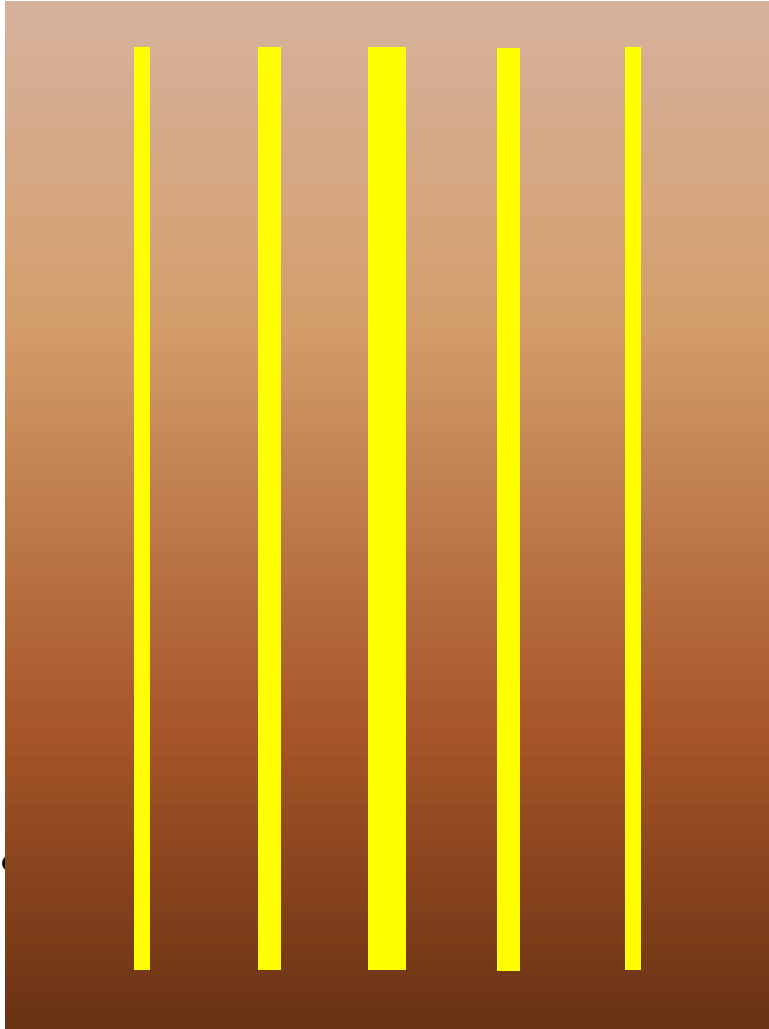
Understanding this intertwining of their fate is where understanding of quantum mechanics Begins.

Wave-particle duality: Bohr's complementarity

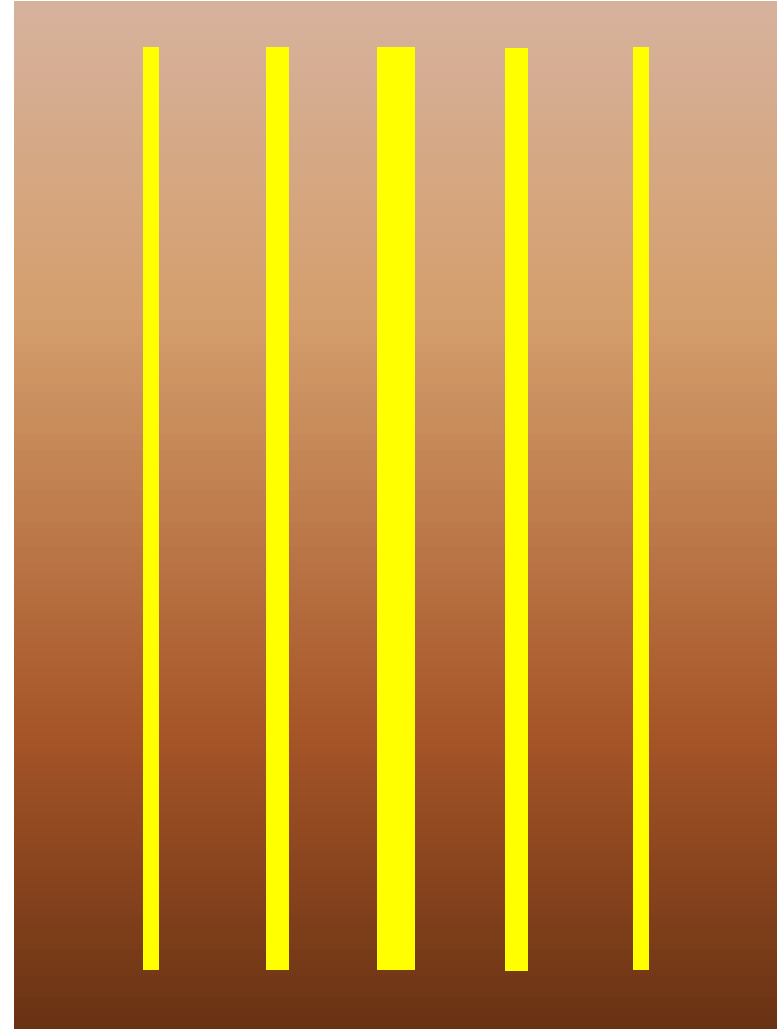


Young's double slit experiment

Wave theory



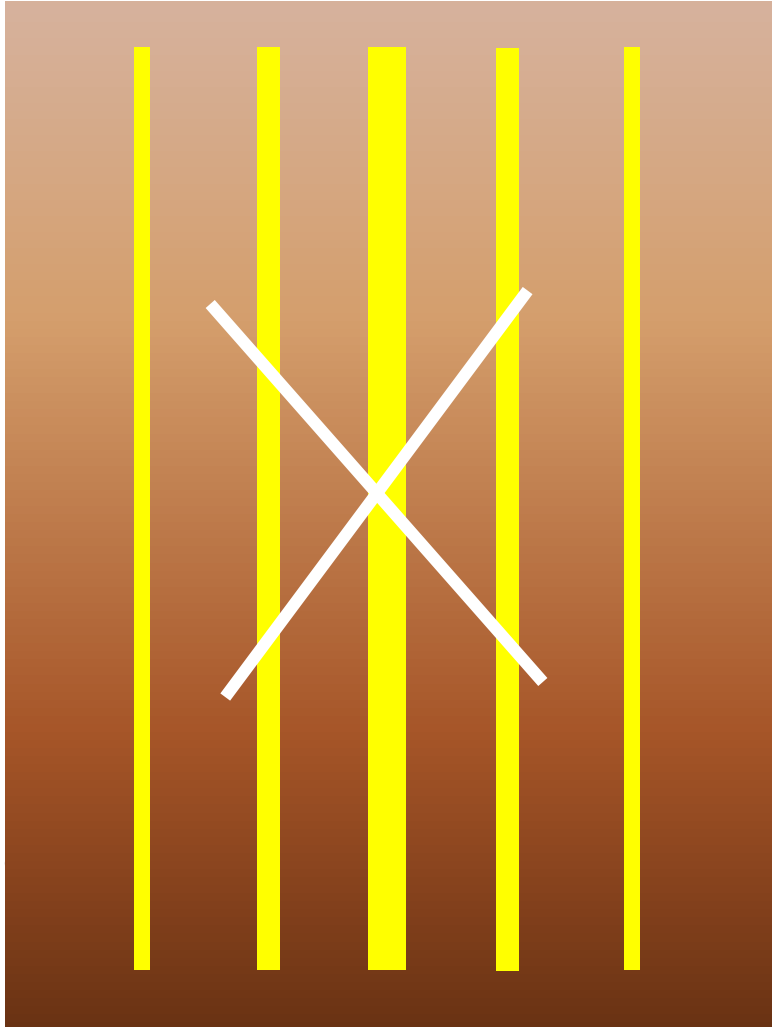
Photon theory



Fringes are observed

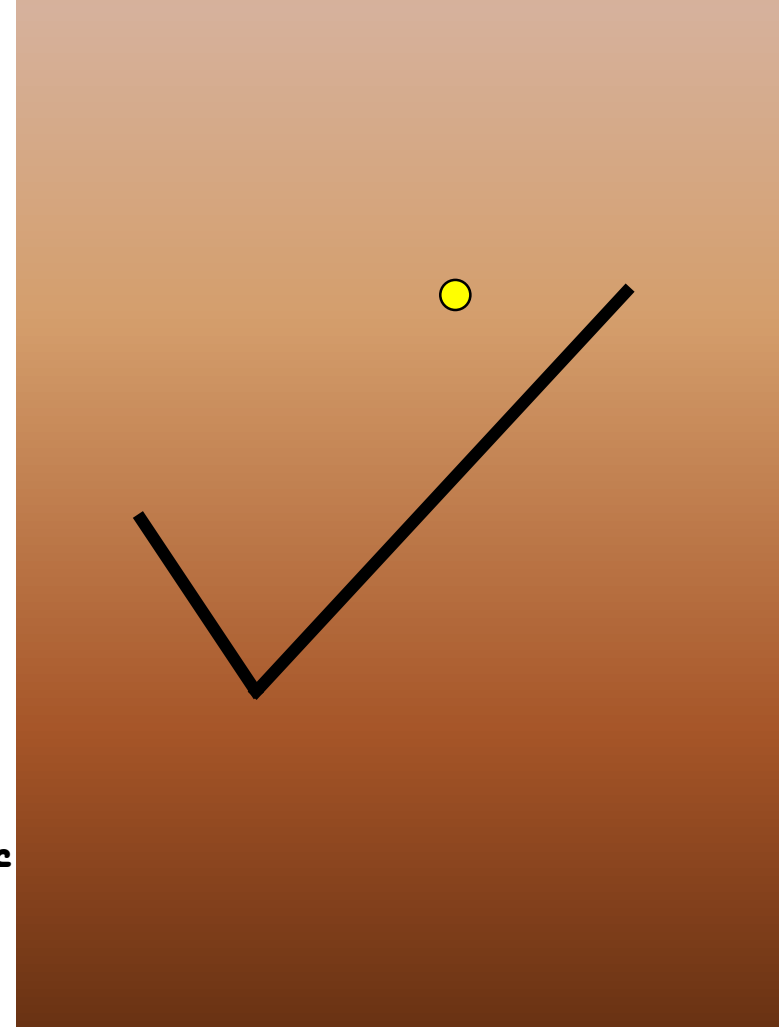
Young's double slit experiment

Wave theory



Fringes *should be* observed

Photon theory



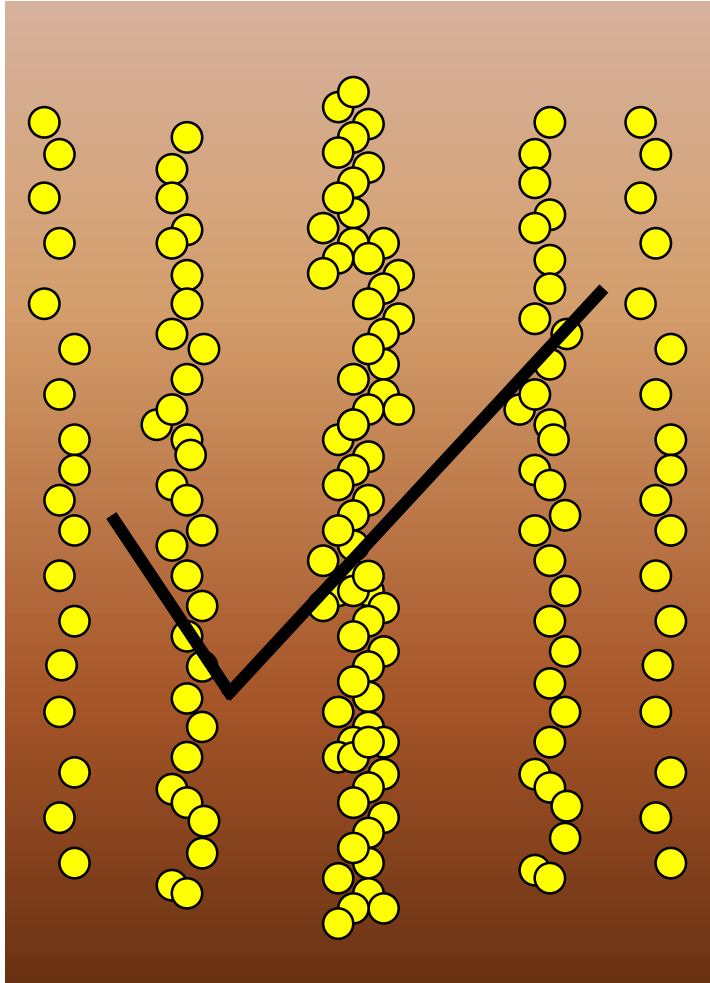
Dots *are* observed



exposure=1 sec

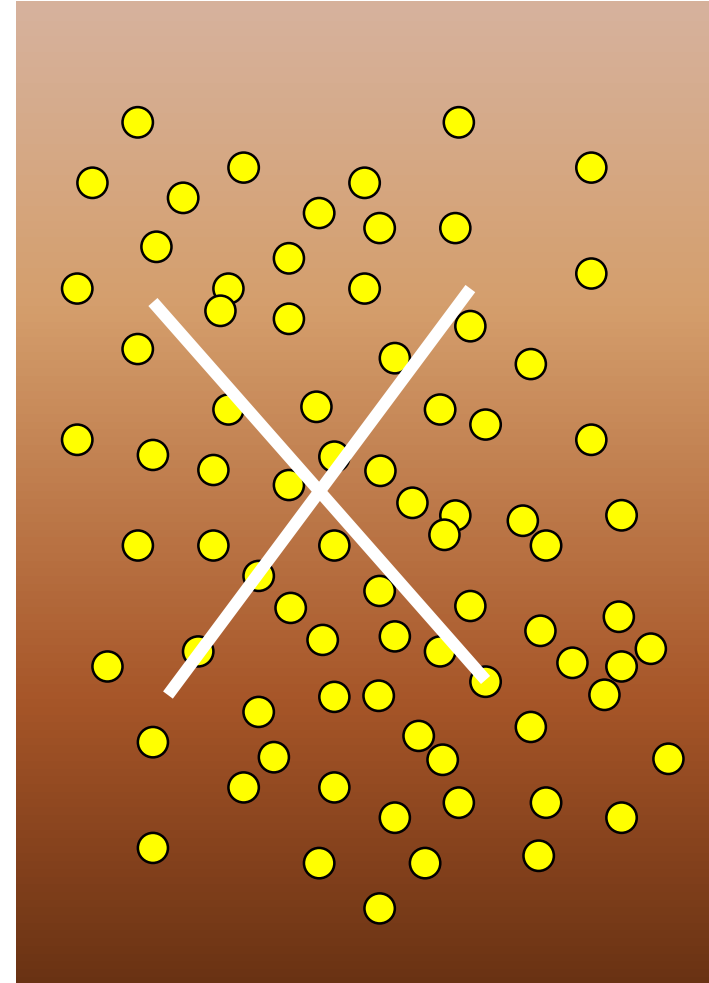
Young's double slit experiment

Wave theory



dots *patterned like*
Fringes are observed

Photon theory



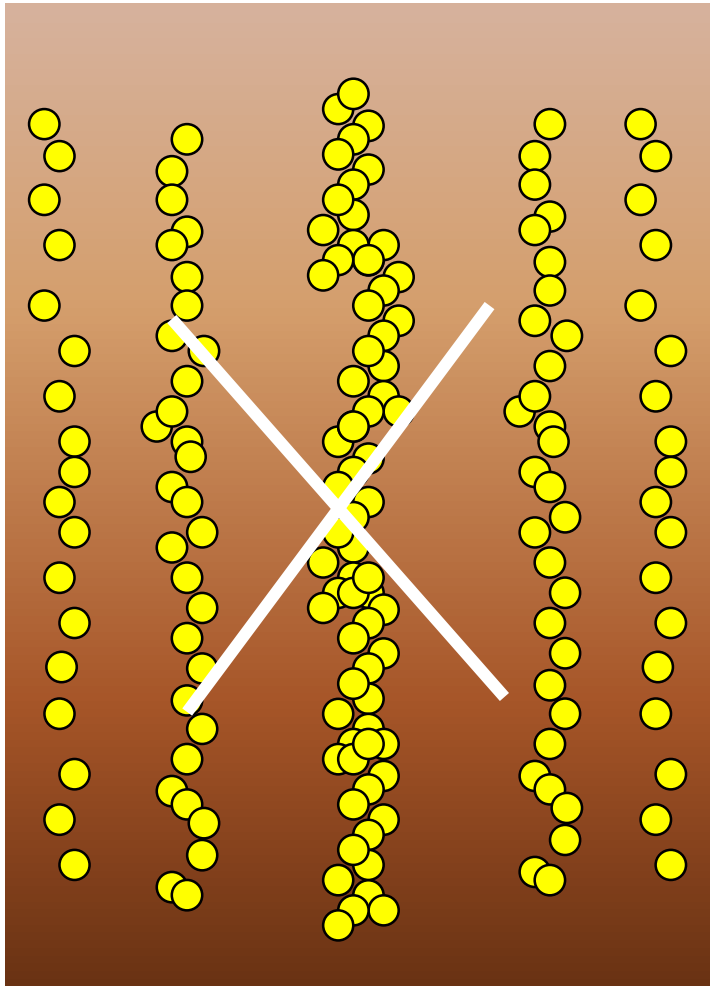
Randomly patterned dots
should be observed



Exposure=5 hrs

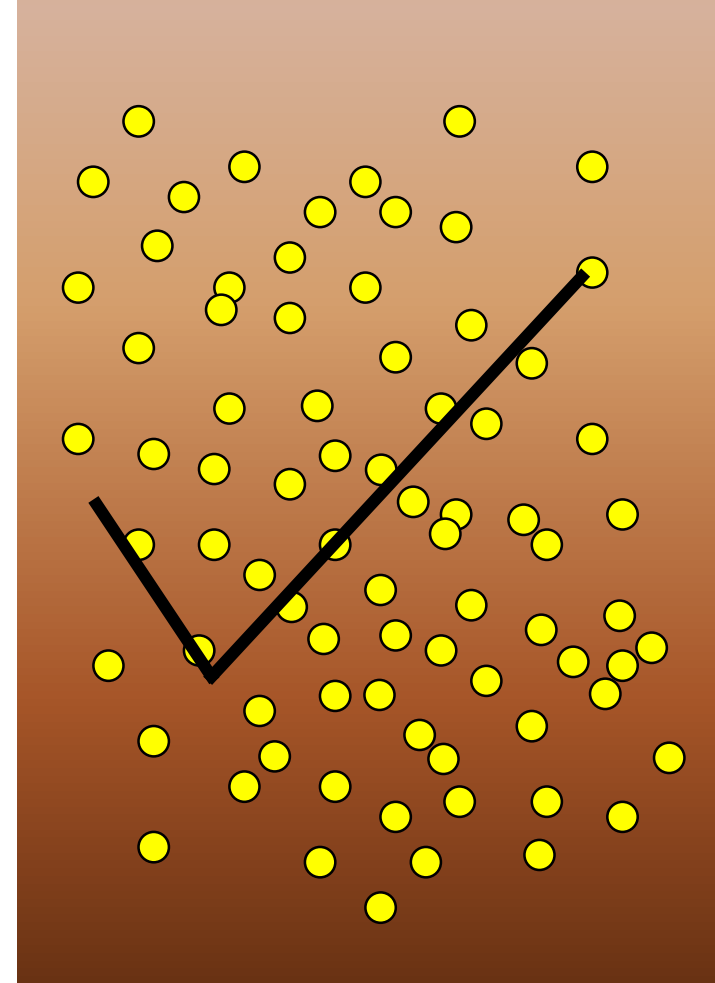
Young's double slit experiment

Wave theory



dots *patterned like*
Fringes should be observed

Photon theory



Randomly patterned dots
are observed



Exposure=5 hrs

Young's double slit experiment... 1803

Moral of the story: wave-particle duality

In 1803, Fresnel vanquished Newton's corpuscular theory of light using this experiment!

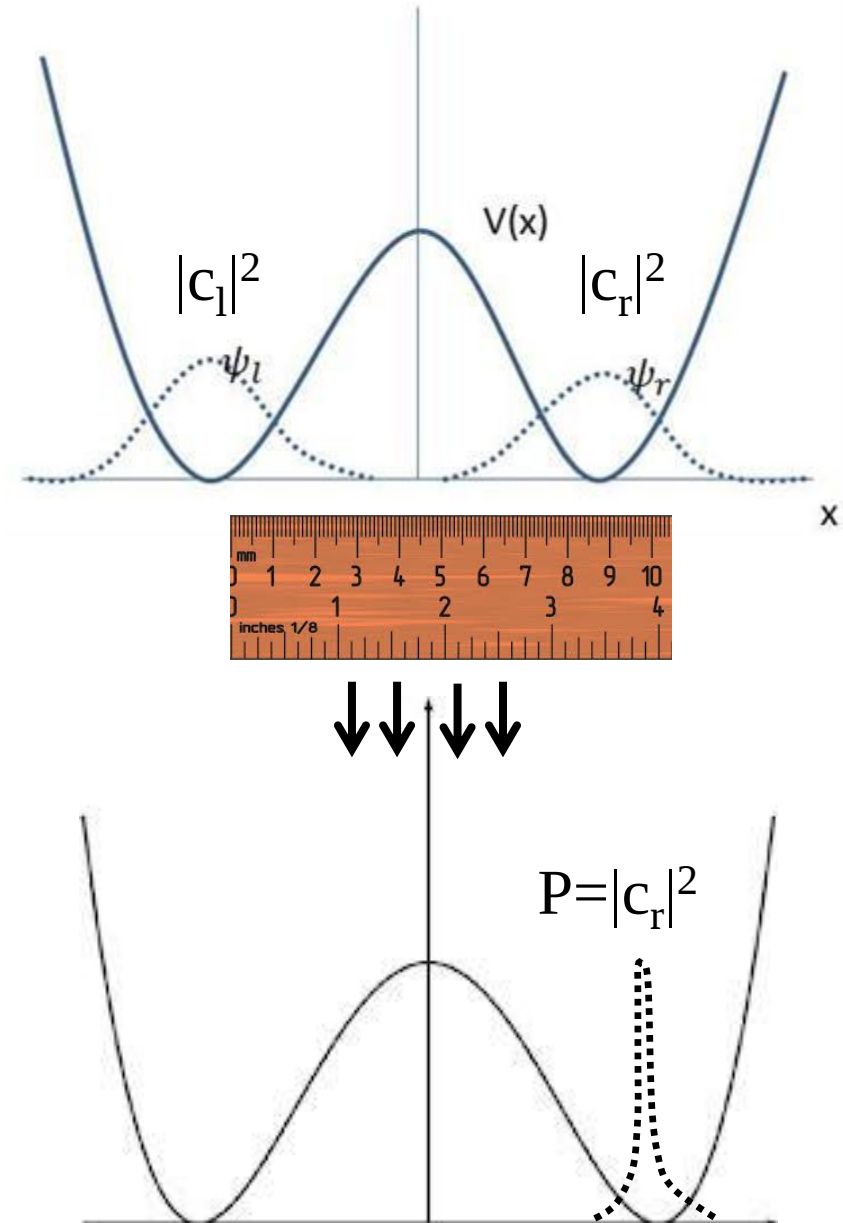
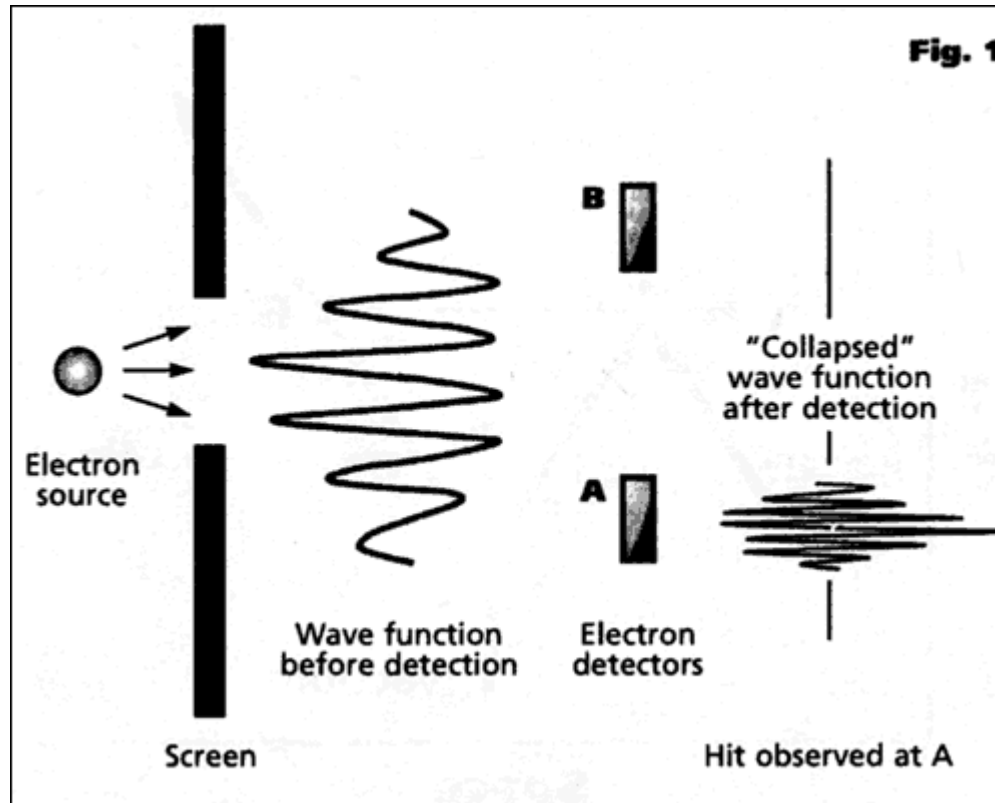
More than hundred years later...

It came back to give a nod to both the nature...

Light behaves simultaneously as a wave and as a flux of particles, Wave enabling us to calculate the probability of the manifestation as a particle. This same thing holds for particles as well.

Thus, measurements..... Do matter!

“Measurement” demands importance!

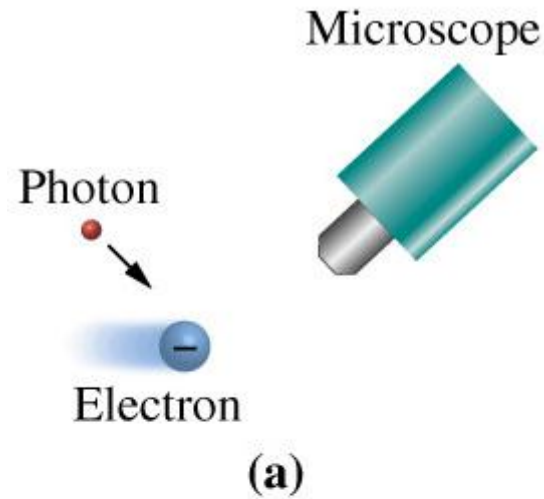


Wave functions collapse!

Measurement is a process.. It affects the state.
Measurement compels the wave to take a stand.

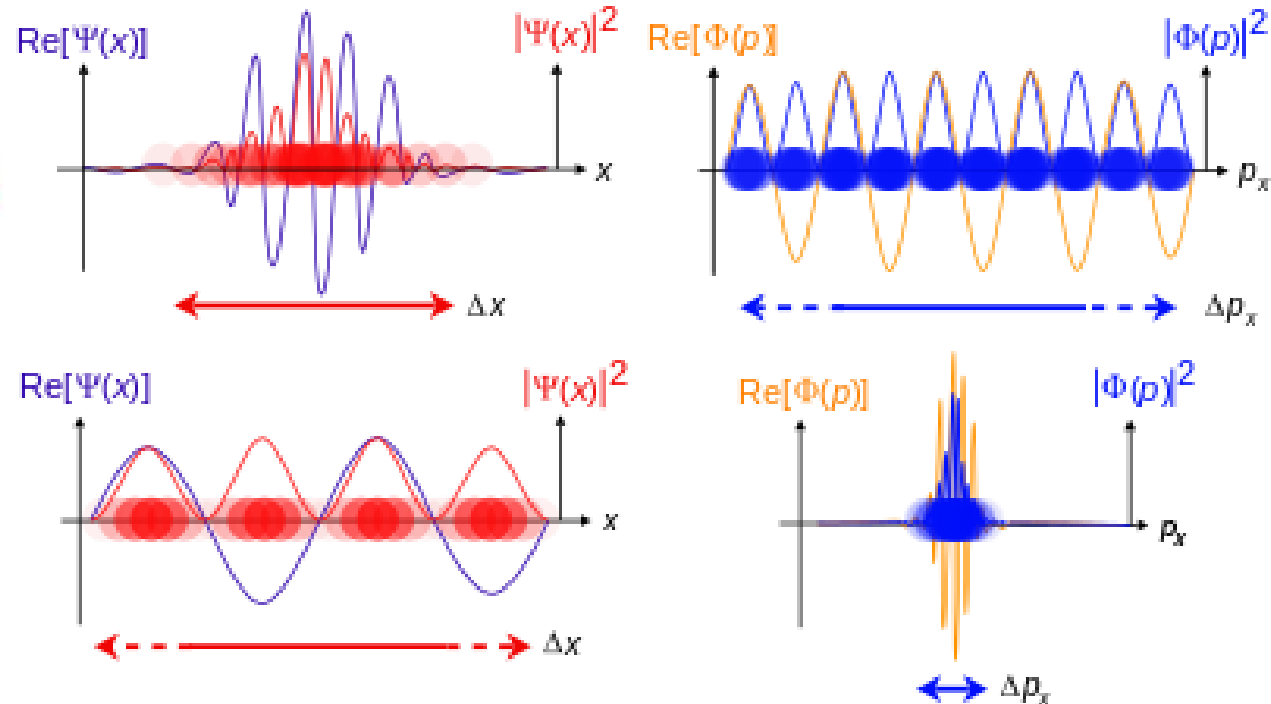
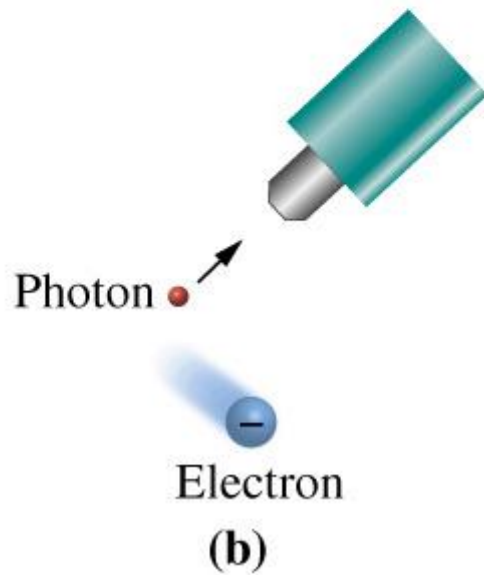
Measurement, actually, produces the result!

Heisenberg's uncertainty principle.. 1927



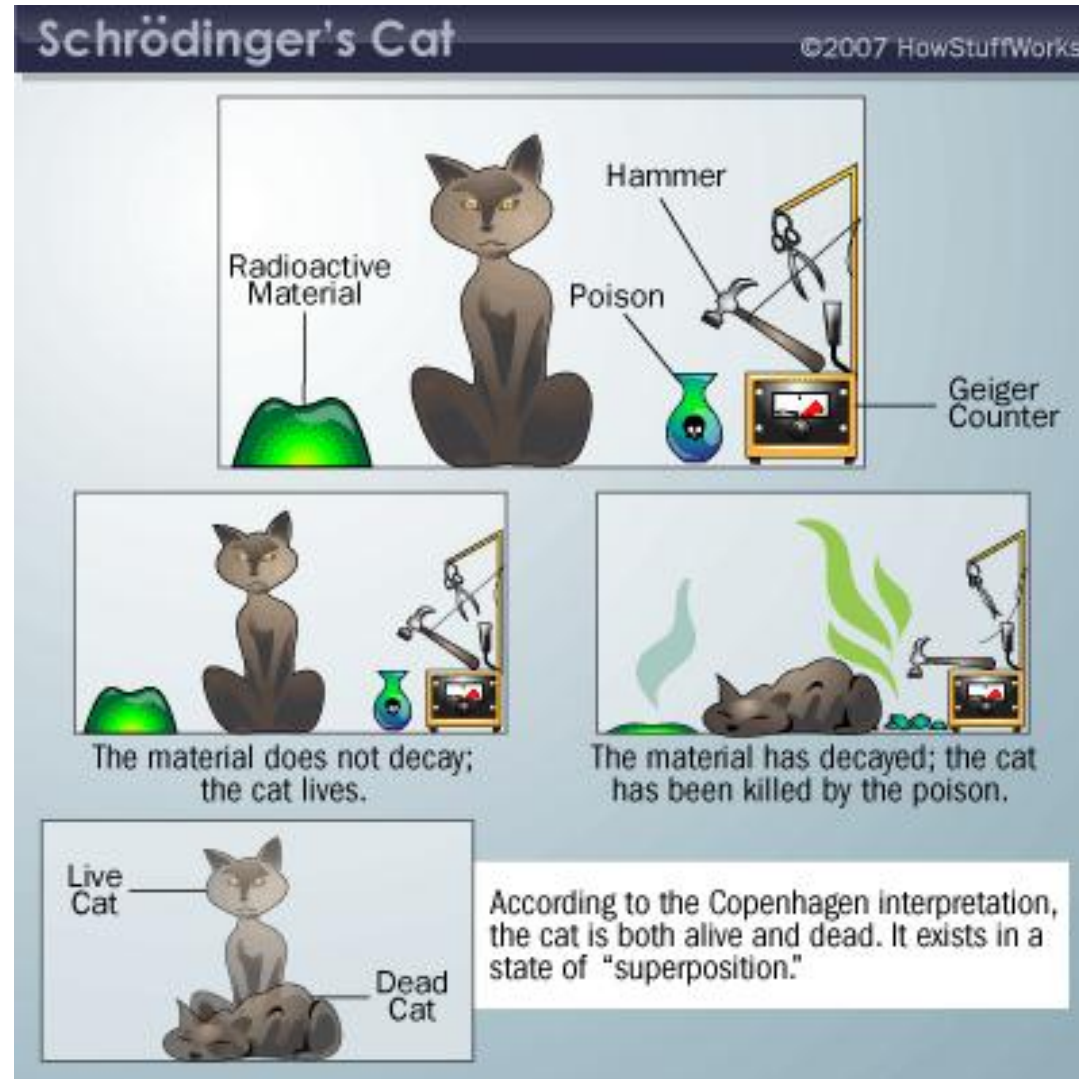
$$\Delta x \cdot \Delta p \geq \frac{\hbar}{2}$$

The uncertainty in position...
...times the uncertainty in momentum...
...cannot be zero; it must be at least this constant



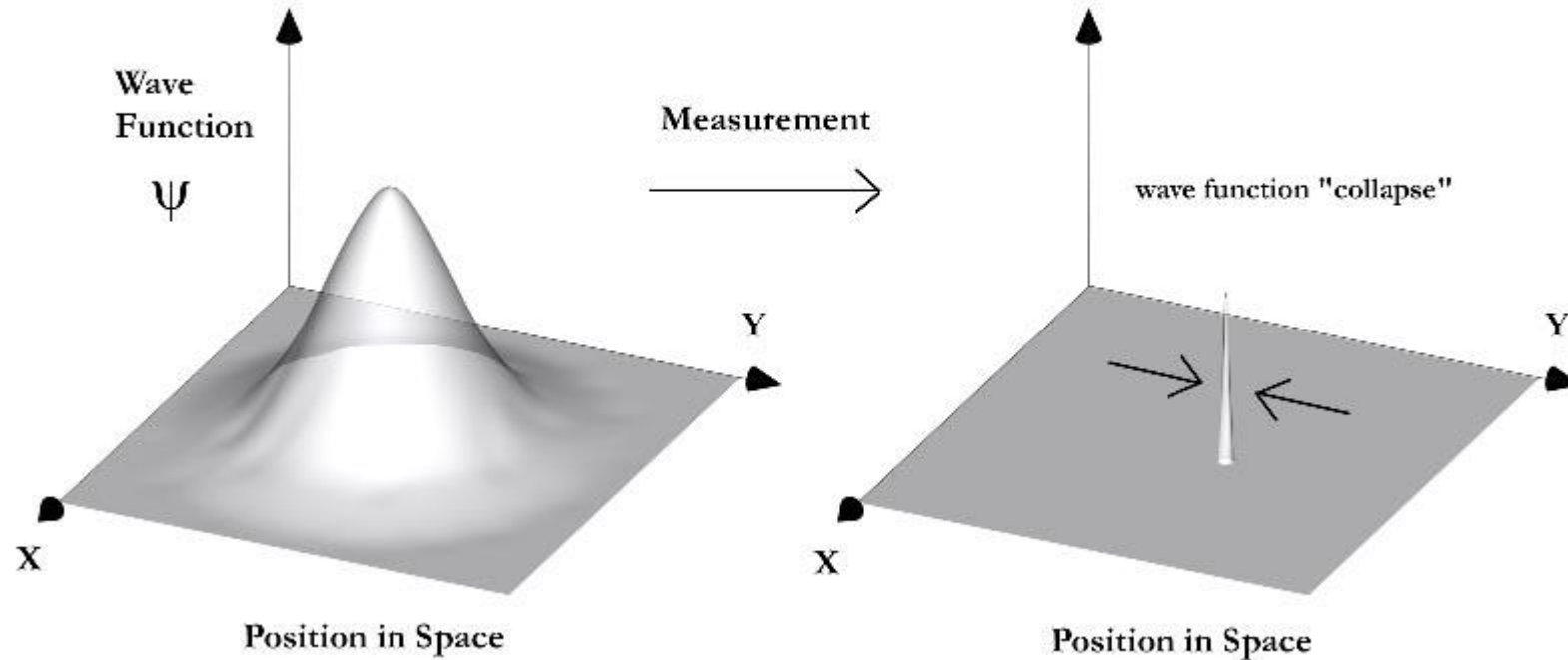
*What we observe is not nature itself,
but nature exposed to our method of questioning!*

Copenhagen Interpretation... Bohr, Heisenberg..



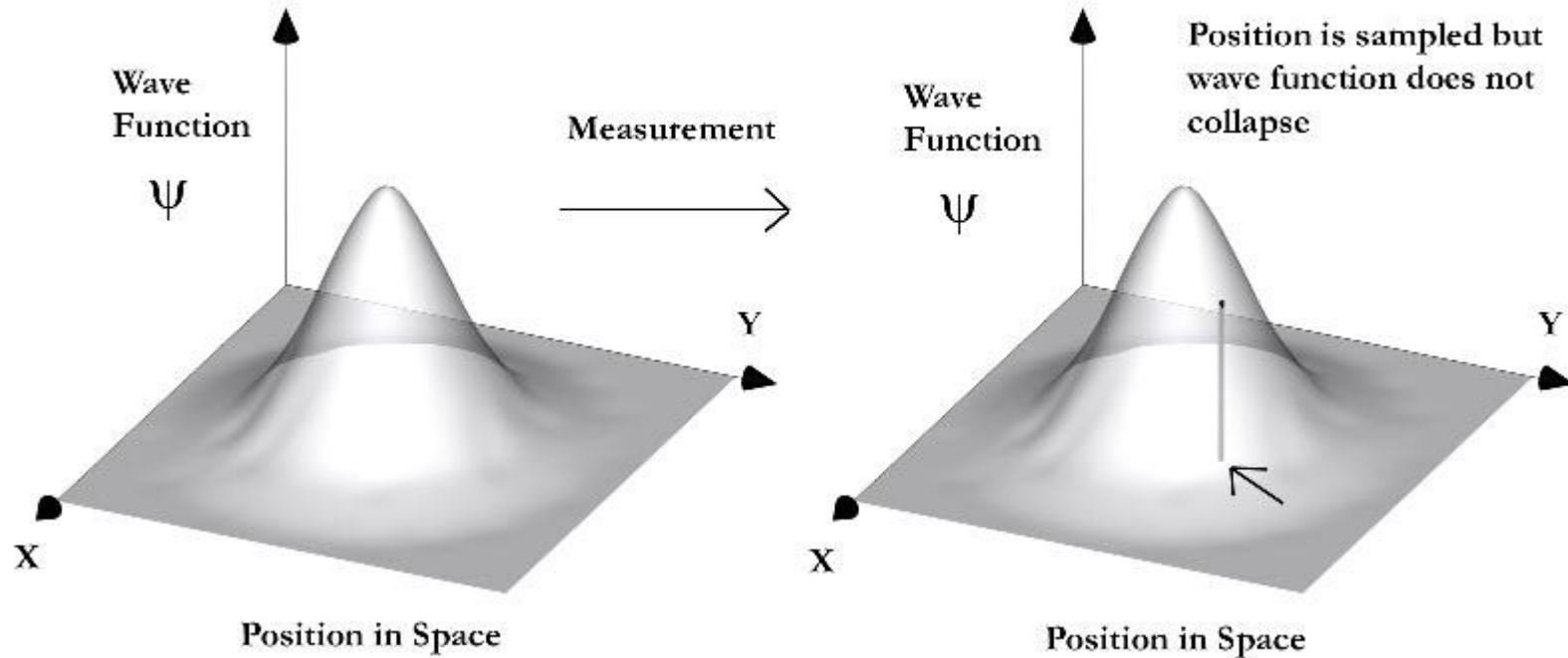
Copenhagen Interpretation... Bohr, Heisenberg..

The Copenhagen Interpretation:

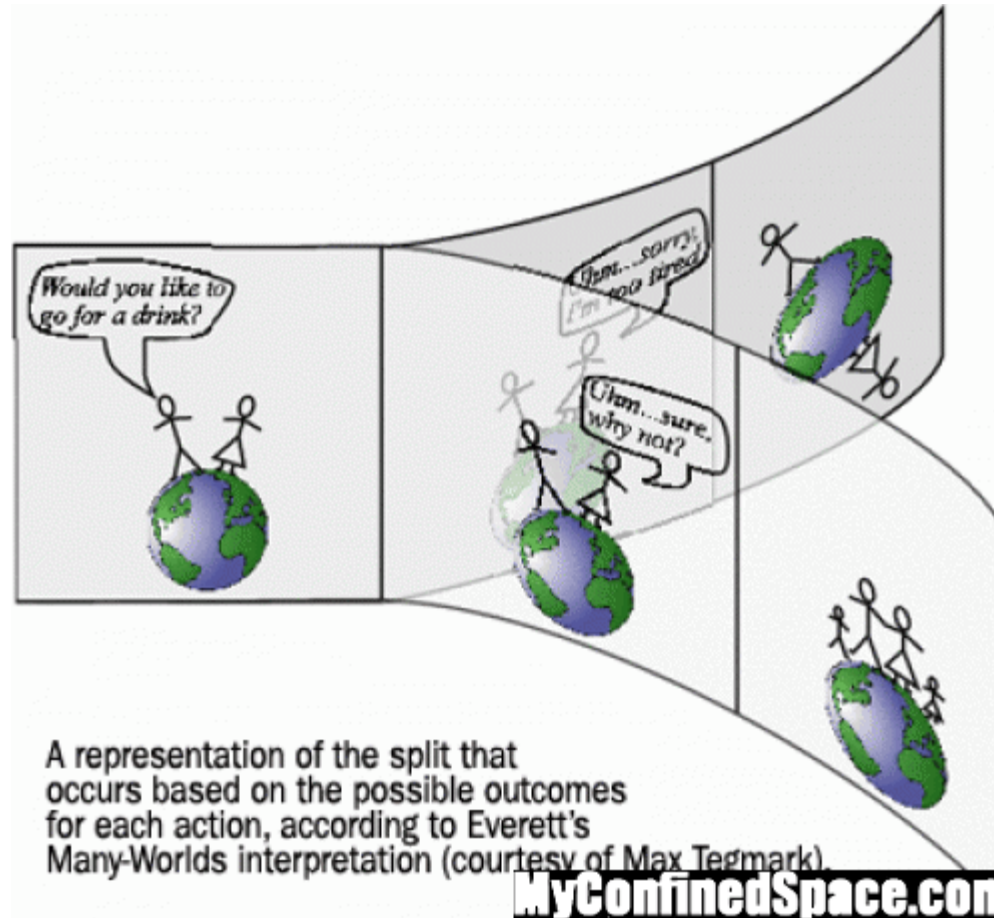


Copenhagen Interpretation... Bohr, Heisenberg..

The Many Worlds Interpretation:



Copenhagen Interpretation... Bohr, Heisenberg..



“Einstein said that if quantum mechanics were correct then the world would be crazy. Einstein was right - the world is crazy.”

— [Daniel M. Greenberger](#)

