2012 Nobel Prizes announced

Particle control in a quantum world

Serge Haroche *and* ***David J. Wineland*** *have independently invented and developed ground-breaking methods for measuring and manipulating individual particles while preserving their quantum-mechanical nature, in ways that were previously thought unattainable.*

Haroche and Wineland have opened the door to a new era of experimentation with quantum physics by demonstrating the direct observation of individual quantum systems without destroying them. Through their ingenious laboratory methods they have managed to measure and control very fragile quantum states, enabling their field of research to take the very first steps towards building a new type of super fast computer, based on quantum physics. These methods have also led to the construction of extremely precise clocks that could become the future basis for a new standard of time, with more than hundred-fold greater precision than present-day caesium clocks.

Figure 1. Nobel Prize awarded for mastering particles. The Laureates have managed to make trapped, individual particles to behave according to the rules of quantum physics.

www.nobel.se has very nice background information for the public

Trapping atoms (ions)

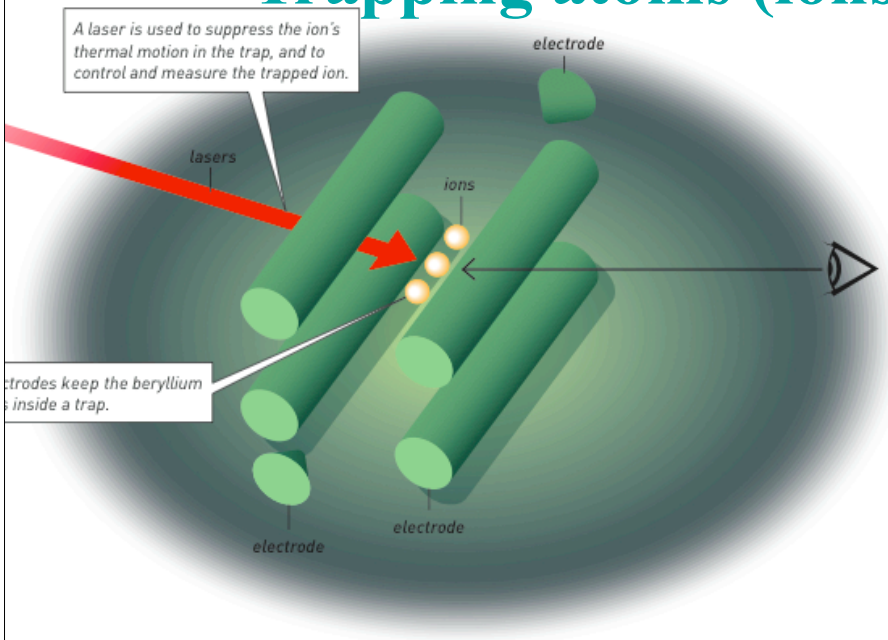


Figure 2. In David Wineland's laboratory in Boulder, Colorado, electrically charged atoms or ions are kept inside a trap by surrounding electric fields. One of the secrets behind Wineland's breakthrough is mastery of the art of using laser beams and creating laser pulses. A laser is used to put the ion in its lowest energy state and thus enabling the study of quantum phenomena with the trapped ion.

Trapping atoms (ions)

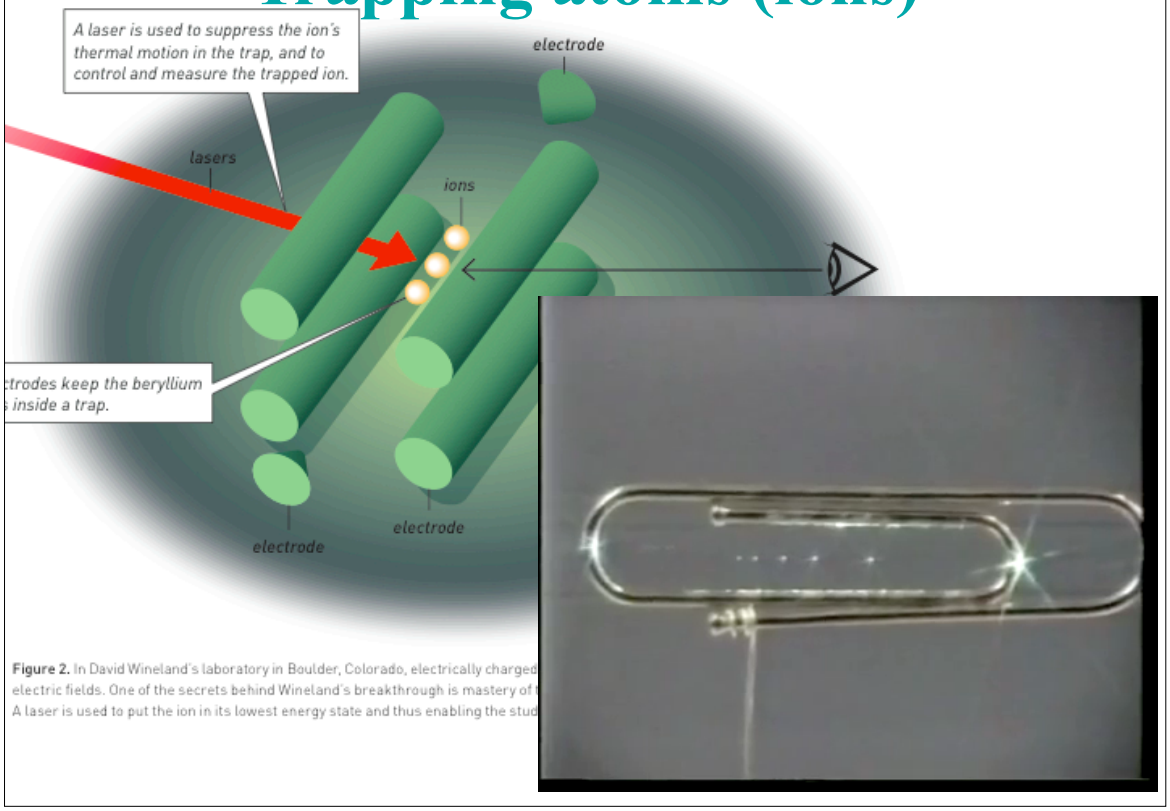


Figure 2. In David Wineland's laboratory in Boulder, Colorado, electrically charged
electric fields. One of the secrets behind Wineland's breakthrough is mastery of t
A laser is used to put the ion in its lowest energy state and thus enabling the stud

Trapping atoms (ions)

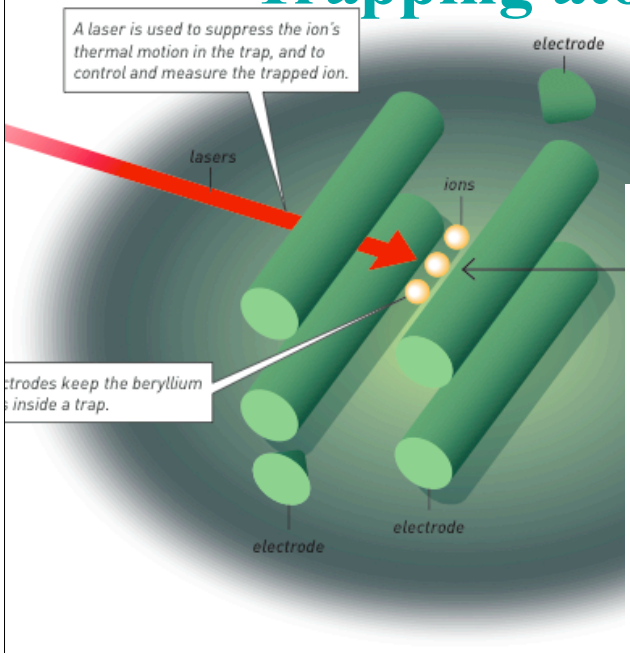


Figure 2. In David Wineland's laboratory in Boulder, Colorado, electrically charged atoms or ions
electric fields. One of the secrets behind Wineland's breakthrough is mastery of the art of usin
A laser is used to put the ion in its lowest energy state and thus enabling the study of quantum

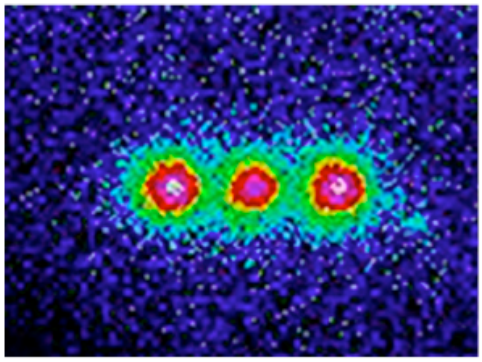
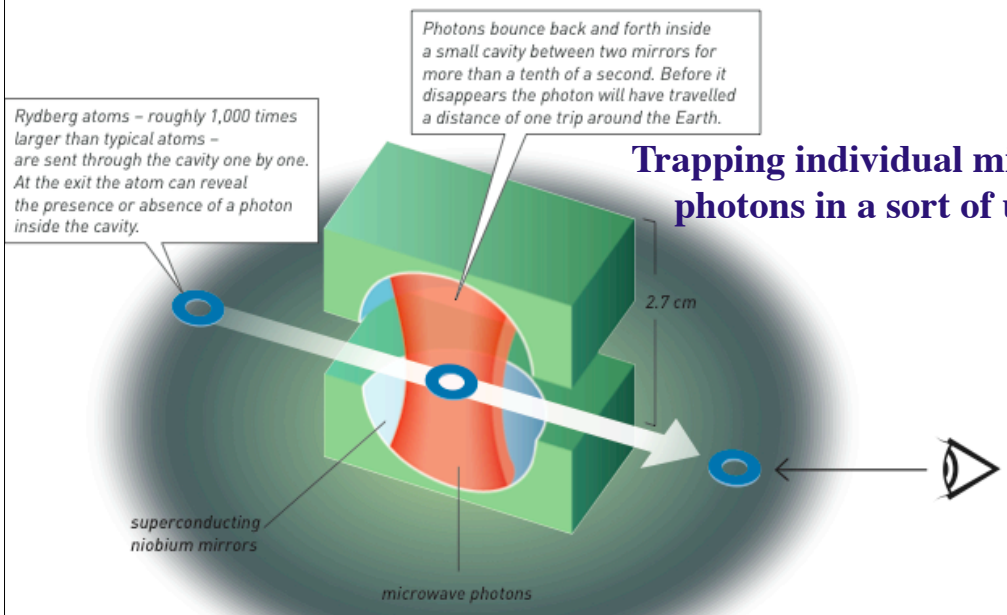


Fig. 2: Image of the fluorescence emitted by three trapped Be^+ ions (National Institute of Standards and Technology image gallery).

Quantum microwaves



Trapping individual microwave photons in a sort of ultracold "oven"

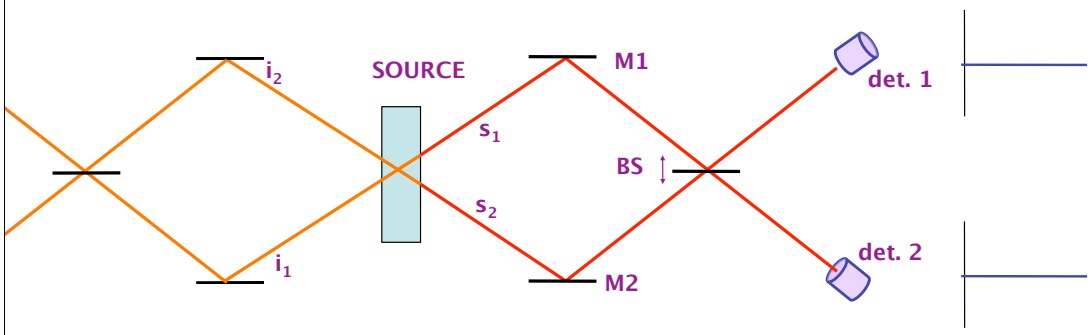
Figure 3. In the Serge Haroche laboratory in Paris, in vacuum and at a temperature of almost absolute zero, the microwave photons bounce back and forth inside a small cavity between two mirrors. The mirrors are so reflective that a single photon stays for more than a tenth of a second before it is lost. During its long life time, many quantum manipulations can be performed with the trapped photon without destroying it.

(Better luck next year, Higgs)

Note: instead of going for the CERN work, which used the highest particle energies ever created by man to discover what we think is the Higgs boson...
this year's prize went to two groups who studied how to get single ions, or the smallest particles of light, at the lowest energies (temperatures) imaginable...

Why this focus on "extremes"?
The highest energies, lowest temperatures, biggest galaxies, smallest particles, et cetera...

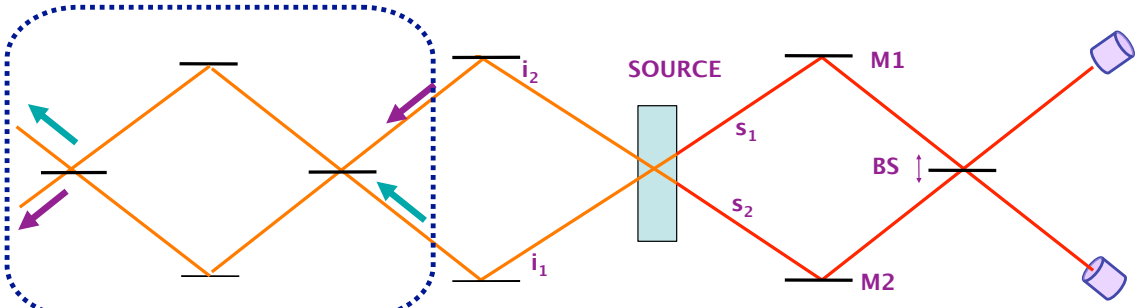
Recall our "microscopic measurement"



The "i" photons provide which-path information, and destroy the interference. Can this information be "erased"?

How long can I wait before "erasing" the information?

Another reason: although not easy,
Humpty-Dumpty could still be put back together...



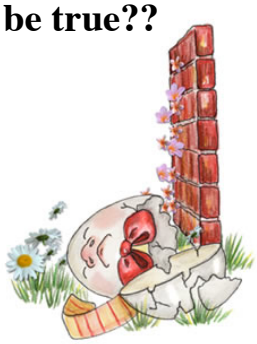
this whole thing is just a Mach-Zehnder interferometer, and can be set up to have "constructive" interference in just the right places

If combining the i photons at a beam-splitter could restore fringes on the right, nothing would prevent me from combining them a year after you looked at your detectors. Could I change whether or not you had seen fringes ?!

Information can be *misplaced*, but never lost!

This is related to the odd fact that in all microscopic theories of physics so far*, time is "reversible"; there is no real difference between past and future, except for the practical difficulty of picking up all the pieces... but can this really be true??

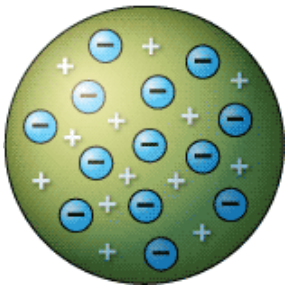
(a topic we'll return to)



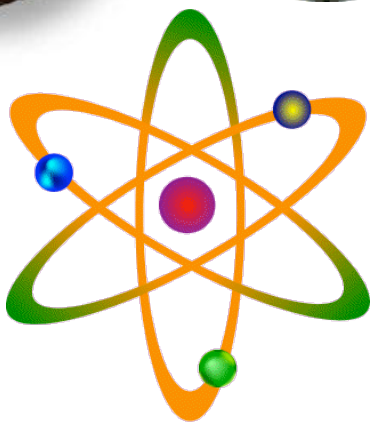
***- almost, but since none of us understands the exception, we'll put it aside for now...**

In parallel - what are atoms made of?

1897: Thomson discovers TV screens (electrons!) -> "plum pudding" atom

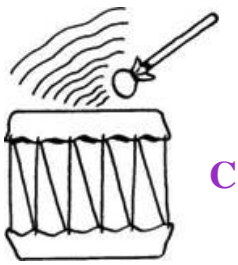


1911: Rutherford discovers the "nucleus" -> "planetary atom"



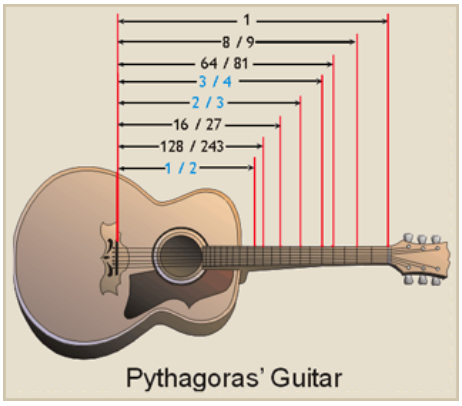
How to study them?

How to study them?

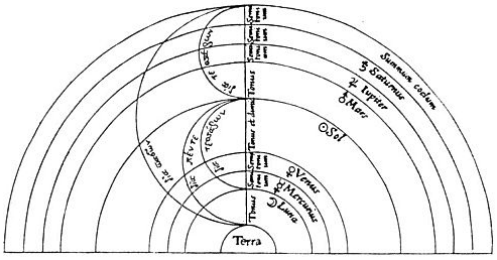


Can you hear the shape of a drum?

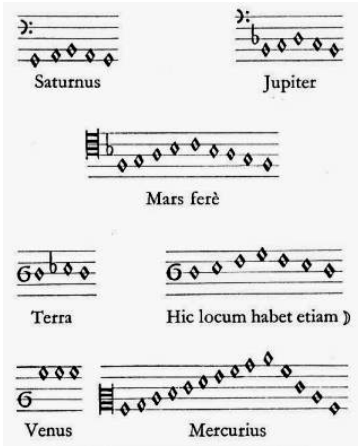
Harmony, music, & physics



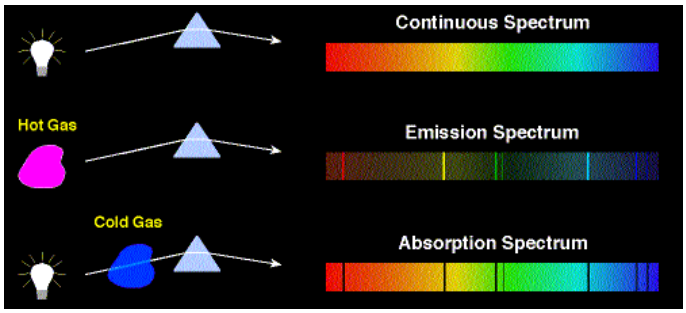
Harmony, music, & physics

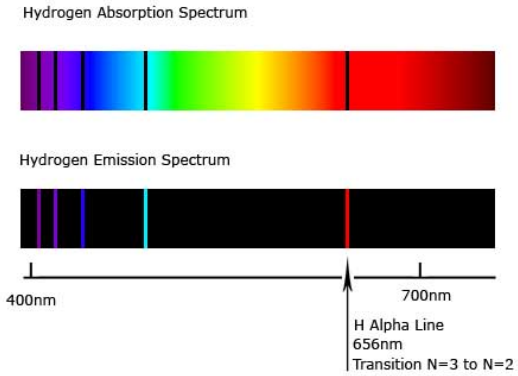



Ioannis Keppleri
HARMONICES
MVNDI
LIBRI V. QVORVM
Lincii Austriæ,



Balmer series (1885-- pre-electron!)





$$\frac{1}{\lambda} = R\left(\frac{1}{2^2} - \frac{1}{n^2}\right)$$

Rydberg -> Bohr

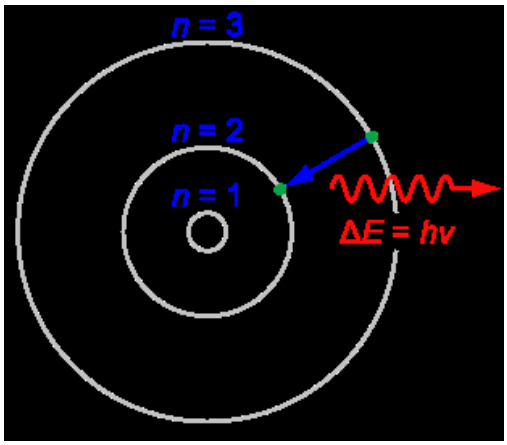
$$\frac{1}{\lambda} = R_{\mathrm{H}}\left(\frac{1}{n_{\mathrm{f}}^{\,2}} - \frac{1}{n_{\mathrm{i}}^{\,2}}\right)$$

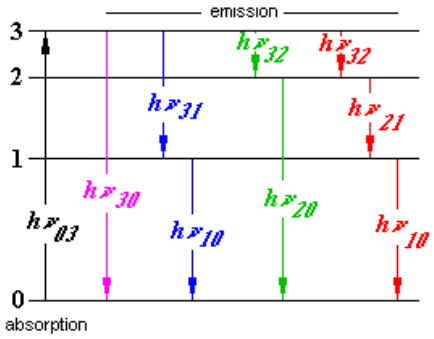
Bohr knows 1/λ is related to the frequency, and Planck & Einstein taught us the frequency was related to the energy.

Why when light is emitted should it carry away the difference between two particular energies?

Rydberg -> Bohr

$$\frac{1}{\lambda} = R_{\mathrm{H}}\left(\frac{1}{n_{\mathrm{f}}^{\,2}} - \frac{1}{n_{\mathrm{i}}^{\,2}}\right)$$

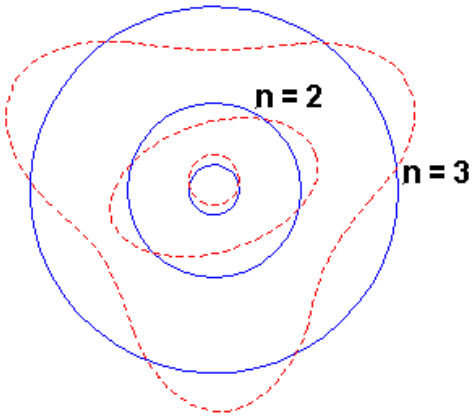




Prince Louis de Broglie:

If light waves act like particles sometimes, then maybe particles of matter also act like waves sometime.

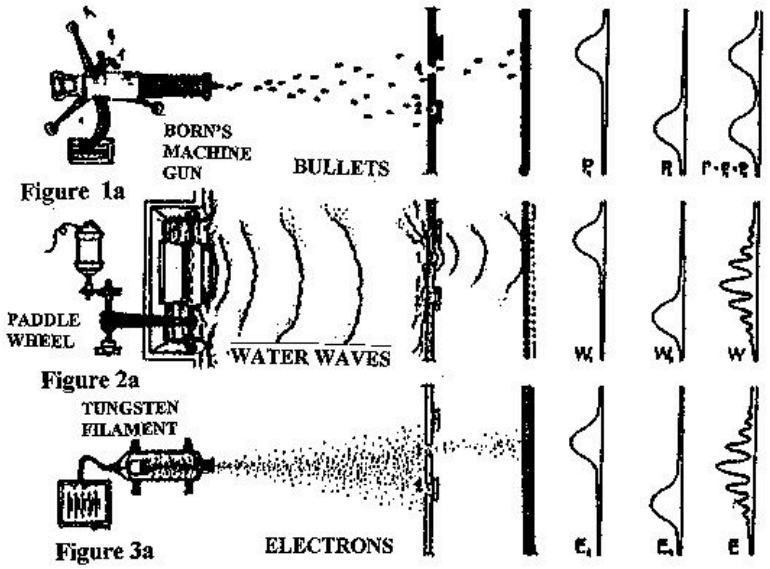
Waves exhibit *resonances* – only specific frequencies they can vibrate at.



The standing de Broglie waves set up in the first three Bohr orbits.

Prince Louis de Broglie (1924):

If light waves act like particles sometimes, then maybe particles of matter also act like waves sometime.



Matter-wave interference

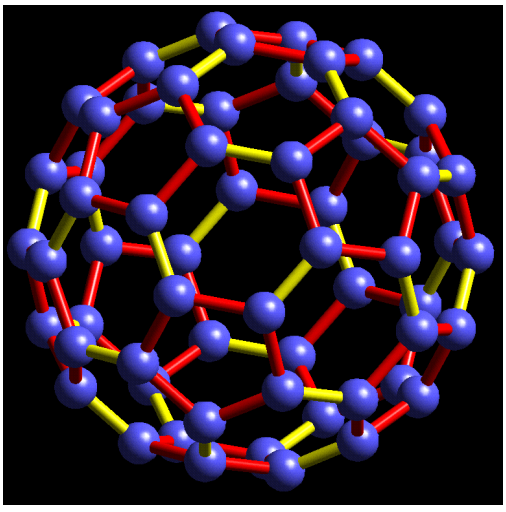
electron "diffraction" - 1927 (Davisson-Germer)

Helium nuclei - 1930s

neutrons - 1940s

whole atoms - 1990s

C60 - 2000s...



Next... viruses?

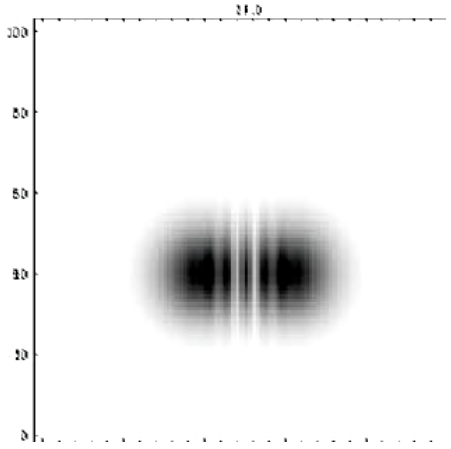
bacteria?

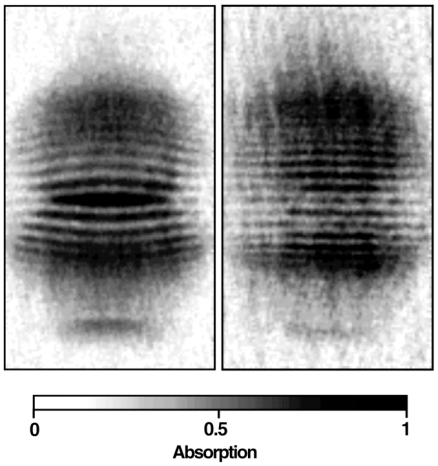
grad students?

Quantum mechanics

Waves of light are also particles...

and particles of matter are also waves!





MIT photo of atoms interfering!
(Relying on lasers and on
Bose-Einstein condensation!)

Everything is a wave and a particle

But what *is* this wave?
Just like the wave that describes a photon particle:
a wave of probability.

Waves of probability

The real meaning of the Feynman rules:

Until a photon (or electron, or other particle) is observed at some point, it has a probability to be anywhere. This wave of "probability amplitude" travels through both slits, interferes, et cetera.

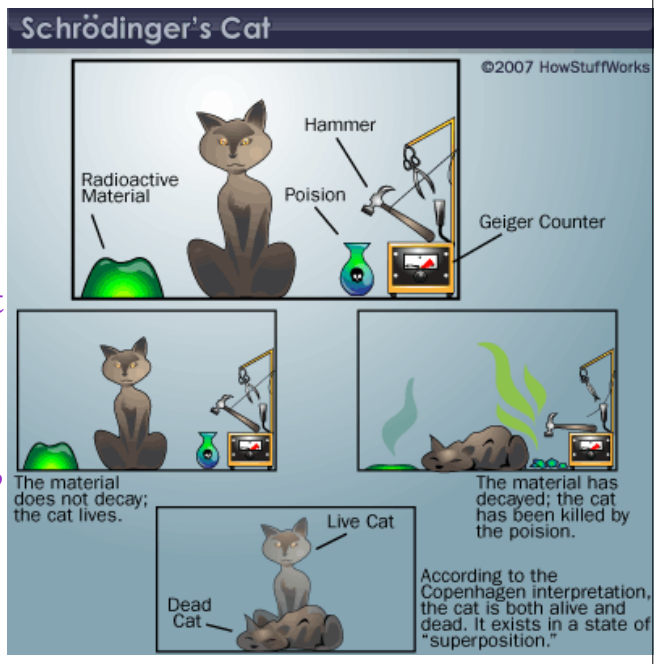
Only when the particle is observed, does this "wave function" *collapse*, meaning that the photon/electron/etc hits one point or another on the screen.

Schrödinger's Cat

If a radioactive nucleus has a 50% chance of decaying, then until we observe it, there's a "decayed" probability wave and an "undecayed" probability wave.

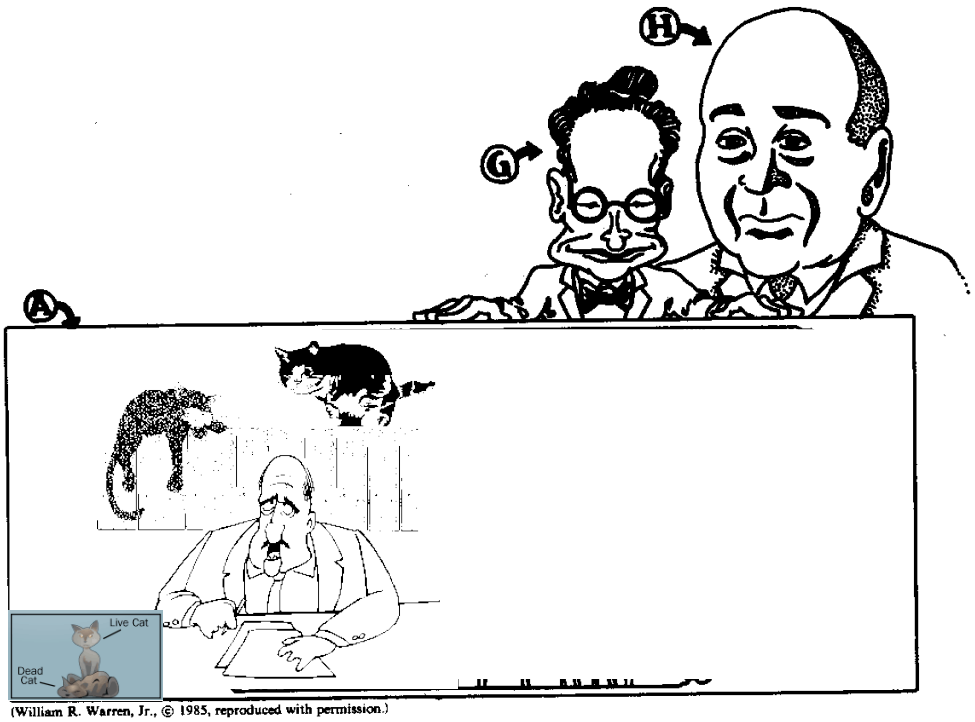
But (asks Schrödinger), what if the decayed nucleus triggers a Geiger counter, releasing a hammer, breaking a vial of poison gas, killing a cat?

Is there simultaneously a probability wave for a live cat and for a dead cat??



Wigner's Friend

Wigner's Friend



(William R. Warren, Jr., © 1985, reproduced with permission.)

The Quantum Measurement Problem

In everyday ("classical") life, we see one thing or another happen, not these strange "probability waves."

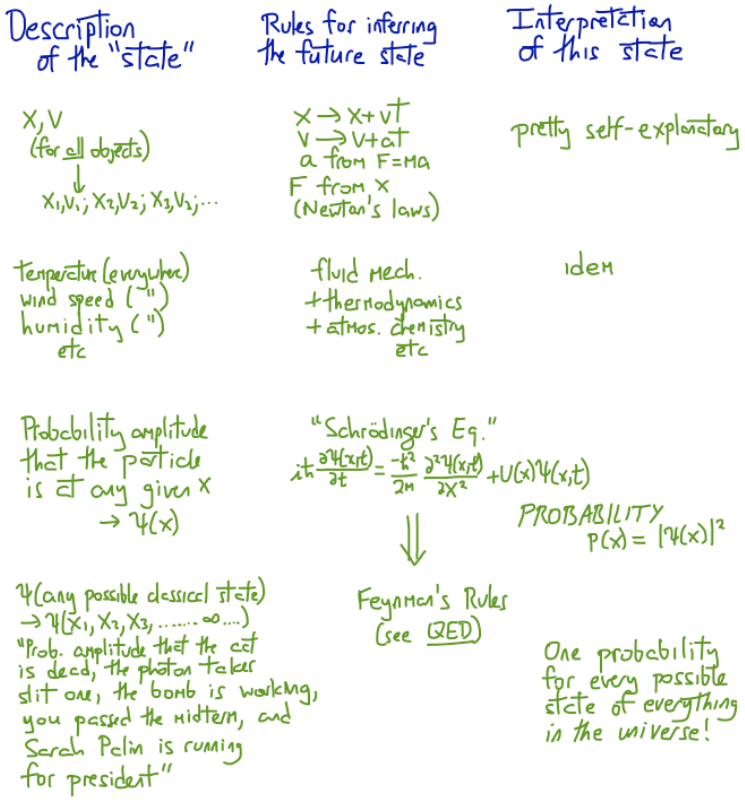
But at what stage does the quantum world become classical? When does the wave function collapse?

What is an observation (measurement)?

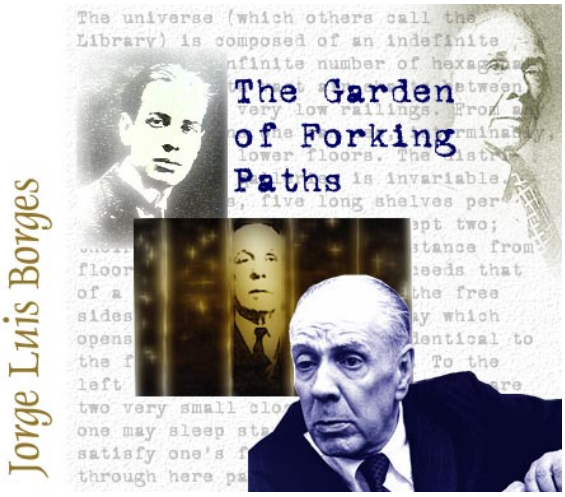
There is no known answer to this question.

Many people believe there *is no classical world*. We may all be part of a huge probability wave, under the illusion that one thing or another happens.

If this is not true (i.e., if collapse really occurs and there is a real boundary between the "quantum world" and the "classical world") no one knows where the boundary lies, and so far, there is *no experimental evidence that any such boundary exists*!



The Garden of Forking Paths ("many worlds" or "many minds")



Differing from Newton and Schopenhauer, your ancestor did not think of time as absolute and uniform . . . this web of time. . . embraces *every* possibility. We do not exist in most of them. In some you exist and not I, while in others I do, and you do not, and in yet others both of us exist. In this one, in which chance has favored me, you have come to my gate. In another, you, crossing the garden, have found me dead.