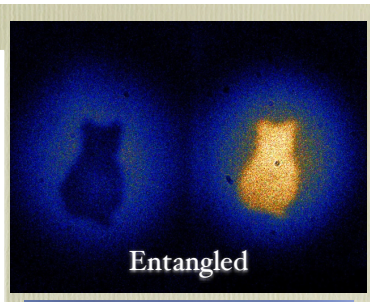
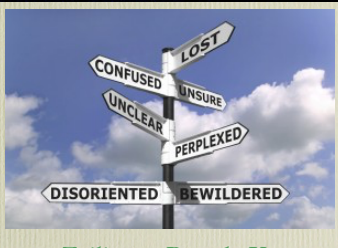
Peter Watson

Carleton UNIVERSITY





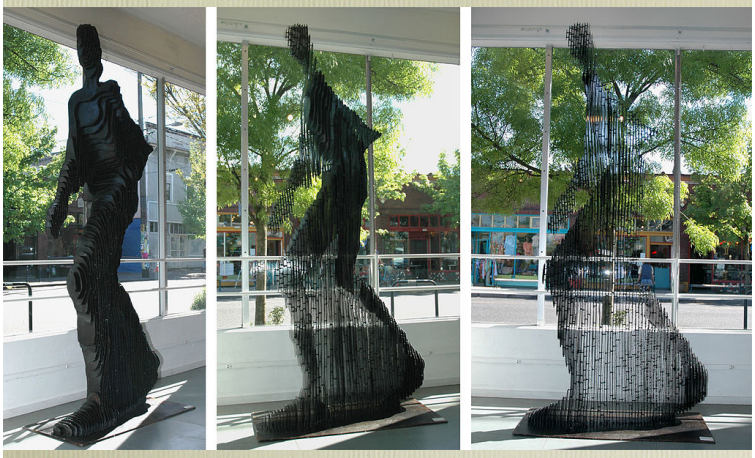
Anton Zeilinger,,Pascale Kavanagh

Quantum Mechanics and Reality

Peter Watson

Julian Voss-Andreae

Quantum Mechanics for Beginners

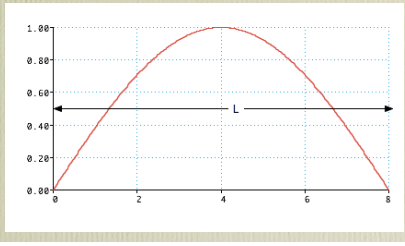


Quantum Man (2006) by Julian Voss-Andreae (Moses Lake, Wisconsin).

- We can calculate measured values with phenomenal accuracy
- E.g. An electron acts like a tiny magnet: exactly how tiny?
- In sensible units
- -1.001159652181 (2006 measured)
- -1.001159652182 (2008 theory)
- So quantum mechanics cannot be ***wrong***

Heisenberg's Uncertainty Principle (1927)

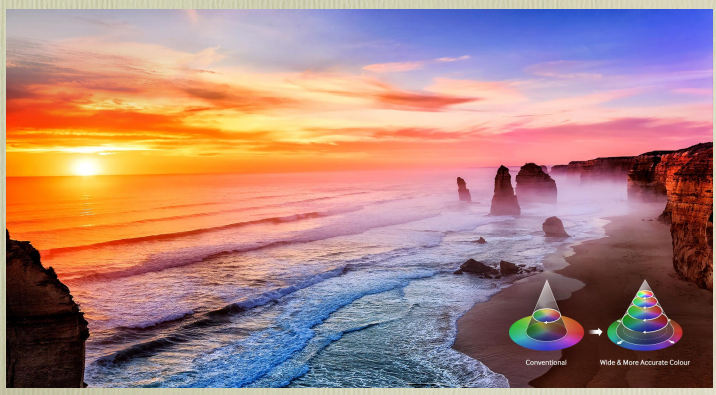
- If an electron is a wave, how can we define its position?
- Suppose we try to measure position of electron by confining it to box, size L
- Uncertainty in position δx= L



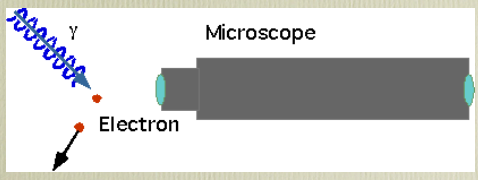
- also an uncertainty in momentum : can be "bouncing" in either direction so
- (uncertainty in position)× (uncertainty in momentum) > Planck's constant
- if we squeeze walls together to measure position better, momentum becomes more uncertain, so energy becomes larger.

Text

"quantum dots" confine electrons ➠ SUHD TV's

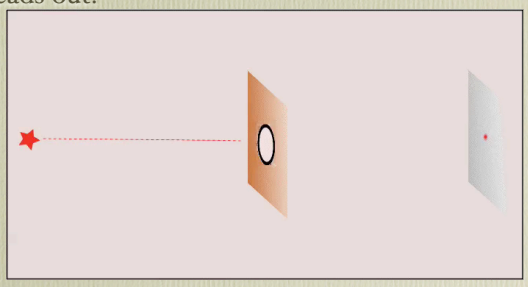


- e.g. try to measure position of electron with microscope
- if we could do it with one photon then the position uncertainty ~ wavelength:
- So decrease wavelength to get position better, but photon carries momentum and some of it gets transferred



Text

- e.g suppose we try to "confine" a photon by making it go through a small hole
- Its momentum becomes more uncertain, so it spreads out!



Patrick Edwin Moran

- This is a fundamental limitation on human knowledge: can always do worse but cannot do better

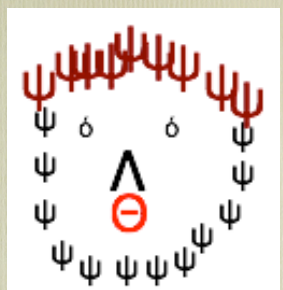
what IS something that is both a wave and a particle?

e.g. a cat

a slipper 

cannot have something that is both a cat and a slipper!

- We have used quantum mechanics as a tool: does it just disguise something deeper?
- Or "Shut up and calculate!"



- I think I can safely say that nobody understands quantum mechanics.
  Richard Feynman

Two tiny problems

1. Which slit did the electron go through??
2. What waves??

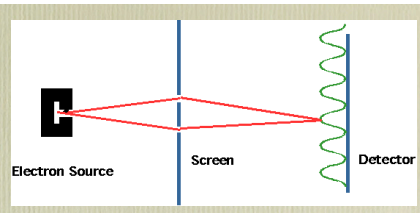
PW

- **Which slit did the electron go through?**

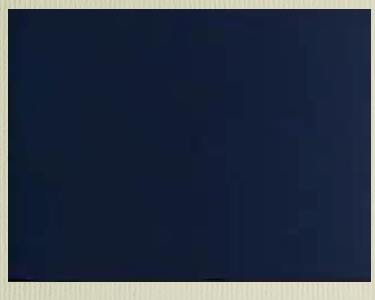
We choose to examine a phenomenon which is impossible, absolutely impossible, to explain in any classical way, and which has in it the heart of the quantum mechanics. In reality it contains the only mystery...Any other situation in QM, it turns out, can always be explained by saying, "You remember the case of the experiment with the two holes? It's the same thing."

Richard Feynman, the Character of Physical Law

- Remember the 2-slit experiment….

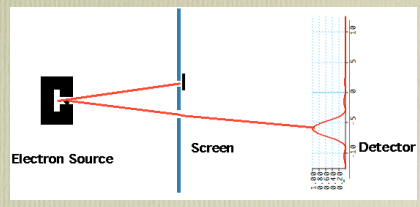


You can even watch how it builds up, one electron at a time

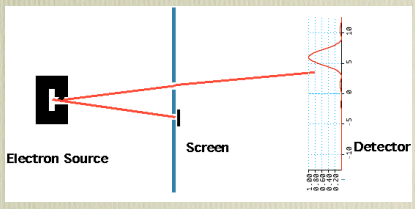


- The electron is a particle, with charge. It must go through one slit or the other...

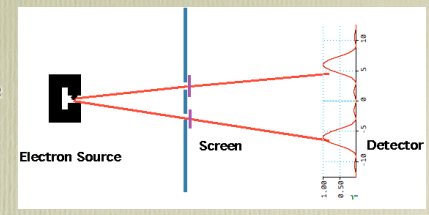
Suppose we close off one slit:



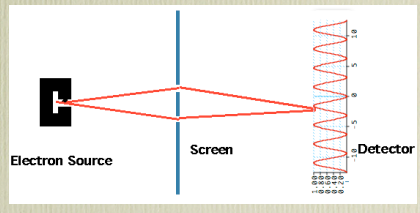
Suppose we close the other slit:



When we add together two one slit patterns, We get this



Not what we get from 2-slits together



- Suppose we get sneaky and allow electron through but check which slit it went through.

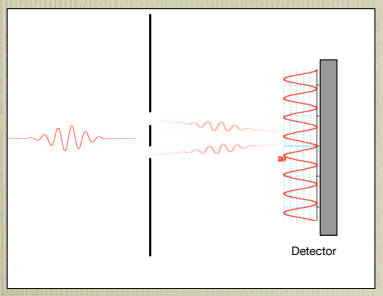
Now we get sum of one slit patterns, but not a 2 slit pattern!

- G.P. Thompson carried out series of experiments using weaker and weaker sources, until he had less than one electron in apparatus at any one time
- Pattern unchanged:
- i.e. not one electron interfering with second, but one electron interferes with itself.
- Huh?

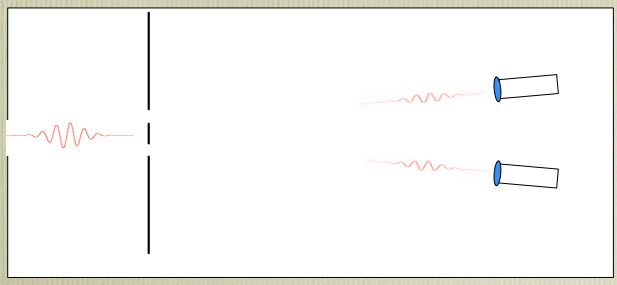
Note in passing JJ Thompson discovered the electron was a particle.
GP Thomson was his son
He discovered it was a wave!

How does the electron/photon know to be a wave or particle?

Will look like a wave: i.e. takes both paths

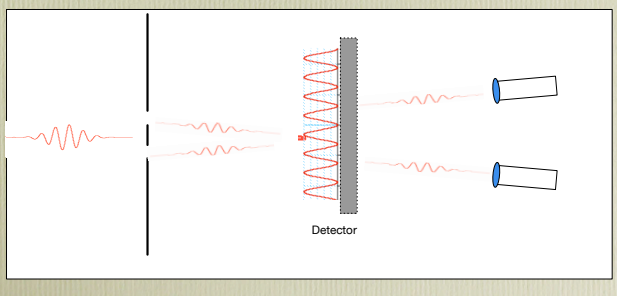


Or we could wait a REALLY long time, and then we will be able to decide which slit it went through, so it only took one path



Or we can decide how to observe it **after** it has gone through the slits

- Delayed-Choice experiment



The observer's delayed choice determines whether the photon has taken one path or two after it has presumably already done one or the other. The experimenter has changed something that in our normal understanding of time-flow has ALREADY HAPPENED. In other words he has changed what happened in the past

Disclaimer:
for technical reasons cannot do the experiment this way, but can be done using a "half-mirror"

"Delayed choice" experiment: Decide how you will observe the electron **after** it has gone through one of the slits...that still destroys the pattern.

Conclusion **We cannot decide which slit the electron went through without destroying the pattern. Observing something fundamentally changes it!**

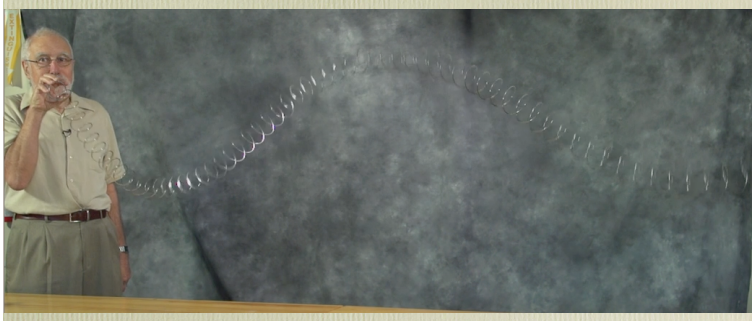
Note

- We see this elsewhere in science:
- e.g. Hawthorn effect in psychology
- Margaret Mead in anthropology

There was a young man who said "God
Must think it exceedingly odd
That this tree
Continues to be
When there's no one about in the Quad"

Kerner: Now we come to the exciting part. We will watch the bullet to see how they make waves ...The wave pattern has disappeared
Because we looked. Every time we don't look, we get wave pattern. Every time we look to see how we get wave pattern we get particle pattern
Hapgood (Tom Stoppard)

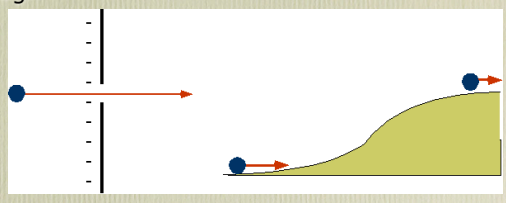
Slinky wave is wave IN a slinky



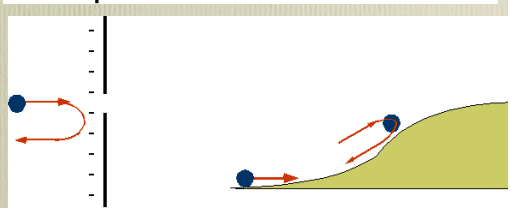
Text

What Waves?

- Obviously the electron is the wave.
- Electron is like a tiny particle: if it hits a barrier it either goes through



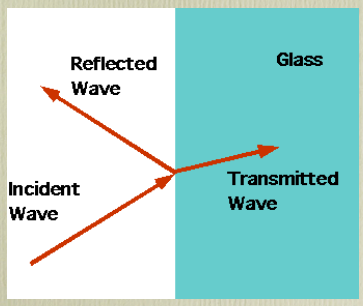
or gets reflected if the energy is too low



PW

What Waves?

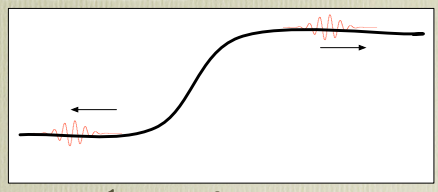
- When waves hit a barrier, they get partially reflected (like light hitting glass).



PW

If electron is literally the wave,

This would imply we see half-electrons



But we don't!

PW

So what is the wave?

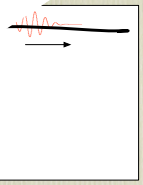
Probability Interp

- Wave represents probability
  at given place

So half

on,

Like flipping a coin!



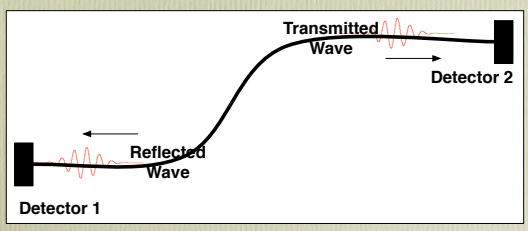
But we need to see the electron…

Probs must add to 1:

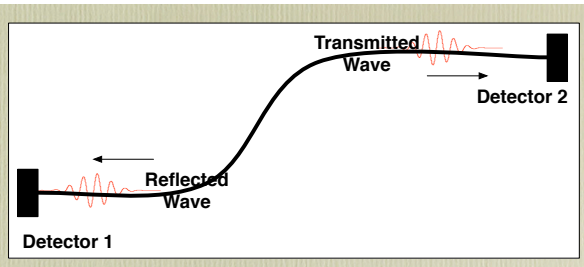
P_1 = prob. that electron hits detector 1:

P_2 = prob. that electron hits detector 2

$P_1 + P_2 = 1$



PW



If (say) P_1 = .5 and we fire 1000 electrons,

- 481 could hit 1
- 519 ---------- 2

- (Maybe)
- 1000 will hit 1 or 2
- But we **cannot** say what any individual electron will do

PW

Classical Determinism

Given state of solar system in (say) 100 A. D., can use Newtonian mechanics to predict earth's position now

Quantum mechanics:

Can only predict most likely (probable) position now.

Morals

1. Macroscopic (i.e. large) objects are predictable, electrons aren't!
2. Cannot ask "what happens?": can only ask "what can we measure?"
3. No reason to assume that rules deduced for macroscopic objects are true for very large/very light/ very fast objects.
4. "What colour is an electron?"

Measurement

In classical mechanics, we believe that a object is the same whether we measure it or not.

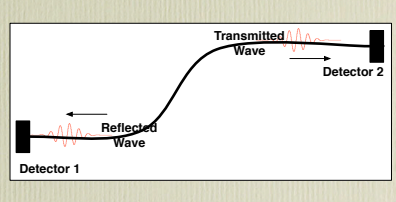
In quantum mechanics, until we have measured it, its condition is indeterminate.

E.g.: suppose we measure the position of a parti and it was here → C

- Where was it just before?
- **Classical Mechanic** At C.
- **Quantum Mechanic** Somewhere: it was only measuring it that fixed its position . Where is a candle flame after it is blown out?

Have we given free will to the electron?

- E.g. go back to our wave function example:
- This seemed to say that the electron gets split in half, but we interpreted it as a probability.
- But when did the electron decide which way it was going?



- **Classical Mechanic** Obviously at the moment it was reflected.

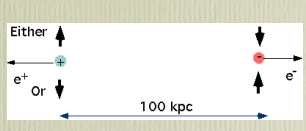
  Quantum Mechanic It is indeterminate until you measure it

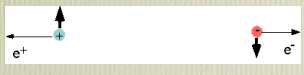
- The Einstein–Podolsky–Rosen paradox (EPR) is a more sophisticated version of this

We can have a particle with no spin which decays into 2 particles with spin

There are two possibilities for the way the spins can arrange themselves: up-down or down-up

Measure one, you know about the other





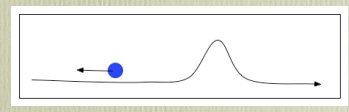
Text

God does not play dice. Einstein

"Hidden variables": underneath quantum mechanics, there is some "clockwork". It only looks random on the surface.

Tunnelling

- A uniquely quantum phenomenon
- If a ball rolls up to a barrier, it gets reflected.



In quantum Mechanics, it can go through the barrier

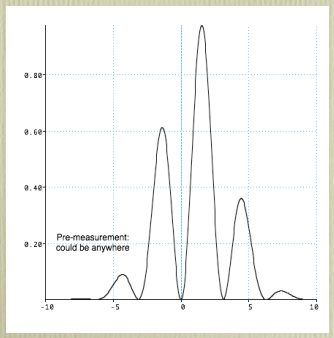
- Except we can't see it when it's inside the barrier!

So does this mean that Q… says electrons can be … places at …

No!

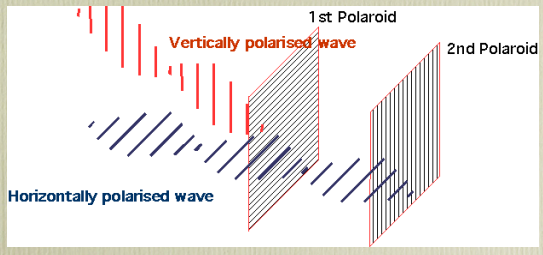
Wave-Function Collapse

- Usual interpretation: measuring something fixes it

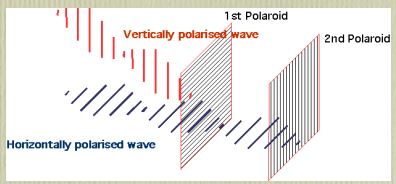


Does this measuring Matter?

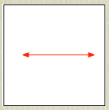
- e.g. consider light going through 2 sheets of polaroid at 90°



Classical Mechanic



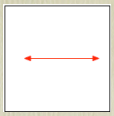
First sheet eliminates all vertically polarized light



Second sheet eliminates all horizontally polarized light
Result: darkness

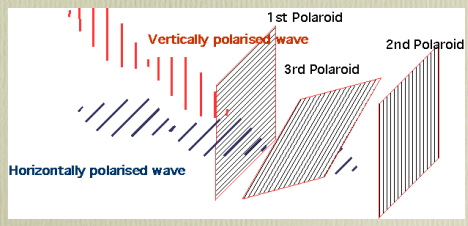
Quantum Mechanic:

First sheet measures how much of light is polarized in horizontal and produces a new wave polarized horizontally



Second sheet measures how much of light is polarized in vertical direction, but there isn't any..
Result: darkness

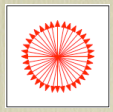
Now insert a third sheet at 45° between the two



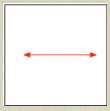
Classical Mechanic:

- First sheet eliminates all vertically polarized light
- new sheet eliminates all light polarized at 45°
- Second sheet eliminates all horizontally polarized light
- Result: darkness

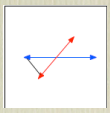
Quantum Mechanic:



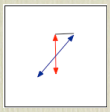
First sheet measures how much of light is polarized horizontally, produces a new wave polarized horizontally



New sheet measures how much of light is polarized at 45°,and produces a new wave polarized at 45°



Second sheet measures how much of light is polarized in vertically, produces a new wave polarized vertically



Result: light
D uuuuuuh!!!!

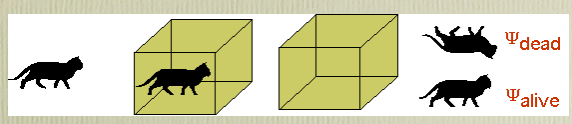
Schrödinger's Cat

was supposed to show the idiocy of people who really believed in quantum mechanics.

A box, with a lid and a single radioactive atom: when the atom decays, cyanide gas is released.

Take a cat
Put it in the box and close the lid.
Is the cat dead or alive?

- **Classical Mechanic** ***Obviously*** it's either dead or alive
- **Quantum Mechanic** It is indeterminate until you measure it . Mor exactly, the cat is a mixture of alive and dead cats: the measurement fixes it.
- **Schrödinger** Don't be stupid.



Both Einstein and Schrödinger were wrong.

The Schrödinger's Cat experiment has been done:

(No animals were injured in the making of this movie!)

One atom: process is totally random, so you can't decide if a one-atom cat is alive or dead without measuring it(!)

Many atoms (10^{29}): constitutes an independent measuring system, so the cat measures it's own deadness

Few atoms (2-20): process becomes steadily more predictable

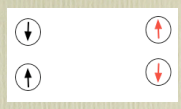
God not only plays dice, but throws them where they cannot be seen. Hawking

They said, "You have a blue guitar,
You do not play things as they are."
The man replied "Things as they are
Are changed upon the blue guitar."

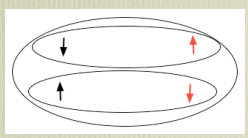
Wallace Stevens

Einstein's mistake

EPR thought the states must be separate



What we have is an "entangled state"

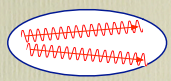


and a measurement destroys it: e.g.

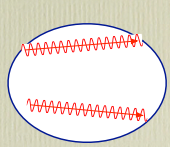
Text

Now we can do clever things!

- Create an entangled pair of photons

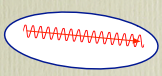


- Send them in different directions



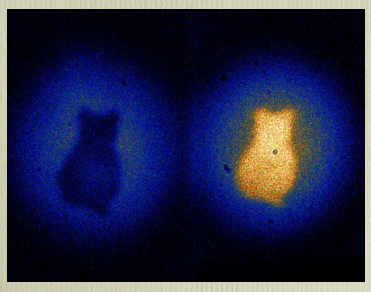
- Absorb one of them

- Observe the other one



Text

- Means you can take a picture with light that has never been near an object.....
- Wouldn't it be fun if we did this with a cat!



Text

And

- We can use entangled
  computing (e.g. D
- and to tele
- and

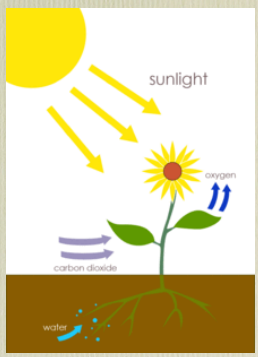
Except not quite yet

Text

Is it new?

All molecules are “quantum-entangled”

Maybe photosynthesis works by entangled electrons



Wikipedia

The link to conscious

Power is the drive
consists of ex
quantum
of the

Well, actually this is from http://sebpearce.com/bullshit/

Text

SOME of the notions that NES® (Nutri… System®) is based on are quantum… information transfer and prio… might be the first biotech… account the entangl… environment th…

Feedback: In fruitloopery's house are many mansions

New Scientist

Measurement

- This “measurement fixes things” is known as the “Collapse of wave function”: obviously very ugly .

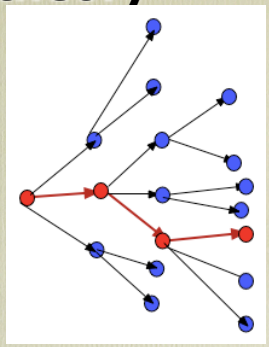
How does the electron know it is being measured?.

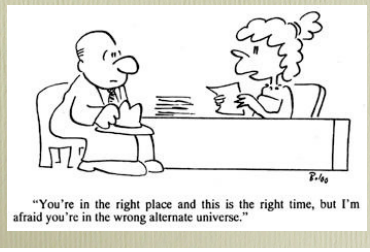
Do we need an actual conscious observer?

Is there a link between consciousness and QM?

Many worlds theory

Many-worlds theory: Everett (1957) . Every time a measurement is made, the universe subdivides into separate universes that correspond to every possible outcome





“You're in the right place and this is the right time, but I'm afraid you're in the wrong alternate universe.”

Avoids observation problems, but not testable (?) and not very economical!

In all fictional works, each time a man is confronted with several alternatives, he chooses one and eliminates the others; in the fiction of Ts'ui Pên, he chooses-simultaneously-- all of them. He creates in the diverse way, diverse futures..which themselves also proliferate and fork.

The Garden of Forking Paths, Borges.

What might have been is an abstraction
Remaining a perpetual possibility
Only in a world of speculation.
What might have been and what has been
Point to one end, which is always present.
Footfalls echo in the memory
Down the passage which we did not take
Towards the door we never opened
Into the rose-garden.

T. S. Eliot (Burnt Norton)

TO think about:

Either Quantum mechanics is correct, and there is no "simpler" system

Or Reality is even uglier than we thought: e.g.

non-local hidden variables: every bit of the universe is involved with every other bit: very Zen, but totally wipes out free will!

???????????

TO think about:

Does it bother you that 21st century technology depends fundamentally on something no-one understands?