Quantum Mechanics and Reality

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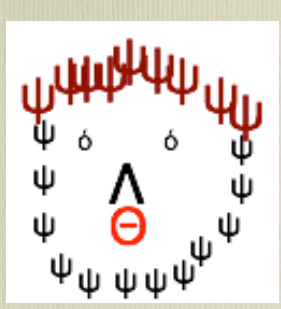
- We can calculate measured values with phenomenal accuracy
- E.g. An electron acts like a tiny magnet: exactly how tiny?
- In sensible units
- -1.001159652181 (2006 measured)
- -1.001159652182 (2008 theory)
- So quantum mechanics cannot be ***wrong***

- No known theory can be distorted so as to provide even an approximate explanation [of wave-particle duality]. There must be some fact of which we are entirely ignorant and whose discovery may revolutionize our views of the relations between waves and ether and matter. For the present we have to work on both theories. On Mondays, Wednesdays, and Fridays we use the wave theory; on Tuesdays, Thursdays, and Saturdays we think in streams of flying energy quanta or corpuscles.

— Sir William Bragg

PW

- I think I can safely say that nobody understands quantum mechanics. Richard Feynman
- We have used quantum mechanics as a tool: does it just disguise something deeper?
- Or "Shut up and calculate!"
- So what is this wave thing?



What is light?

Particle? Newton, Descartes
Kerner: Look at the edge if the shadow. It is straight like the edge of the wall that makes it. This means light is ..little bullets. Bullets go straight.
Hapgood (Tom Stoppard)

Wave? Young, Huyghens
Kerner: When you shine a light through two little gaps, side by side, you don't get particle patterns like for bullets, you get wave patterns like for water. The two beams of light mix together
Hapgood (Tom Stoppard)

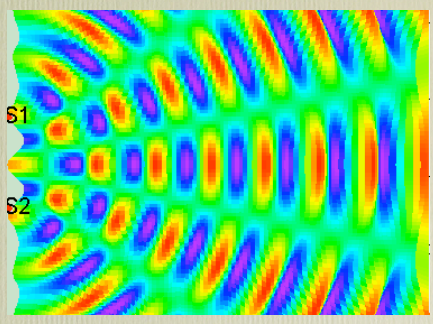
Yes? Planck/Einstein
Light travels as wave, but arrives and departs as particle

- **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."

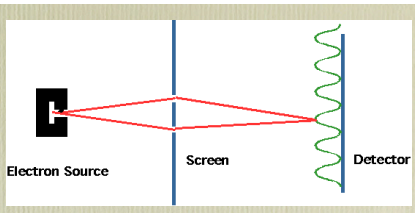
Richard Feynman, the Character of Physical Law

•Like this

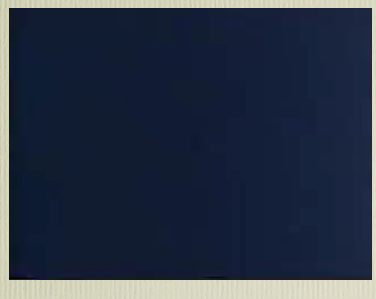


Wikisource

- We can now do this with electrons: Very low energy electrons pass through slits and hit detector (e.g. photo plate) and give 2-slit interference pattern

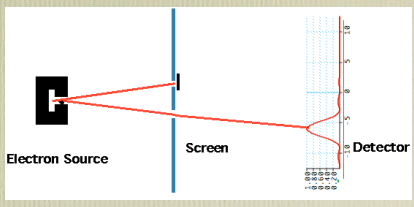


You can even watch how it builds up, one electron at a time

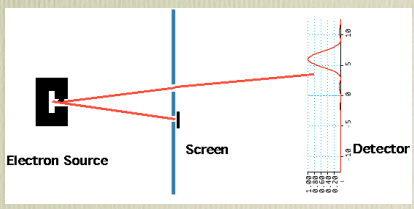


- The electron is a particle, with charge. It must go through one slit or the other...

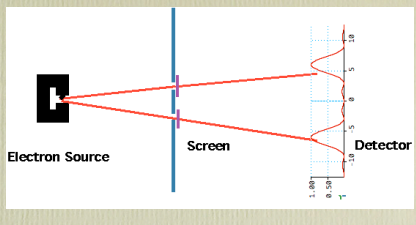
Suppose we close off one slit:



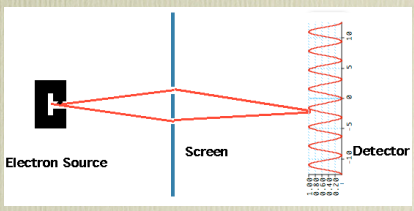
Suppose we close the other slit:



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!

More worrying than this: we can do a "delayed choice" experiment: don't try to observe the electron until **after** it has gone through one of the slits...that still destroys the pattern.

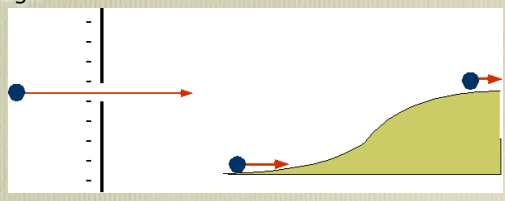
Conclusion **We cannot decide which slit the electron went through without destroying the pattern. Observing something fundamentally changes it!**

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"

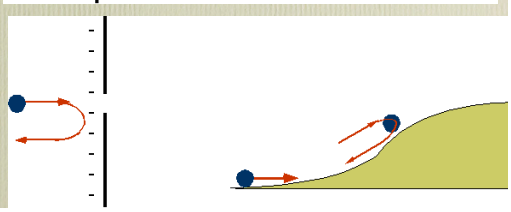
Kerner: Now we come to the exciting part. We will watch the bullet to see how they make waves ...The wave pattern has disappeared
Because we looked. Every time we don't look, we get wave pattern. Every time we look to see how we get wave pattern we get particle pattern
Hapgood (Tom Stoppard)

What Waves?

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

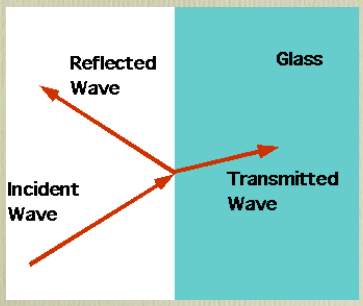


or gets reflected if the energy is too low

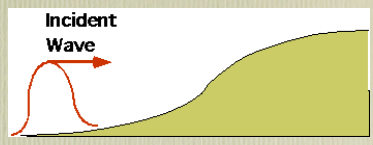


What Waves?

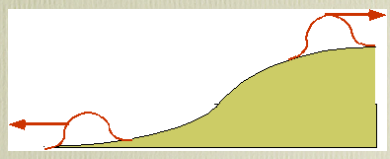
- When waves hit a barrier, they get partially reflected (like light hitting glass).



If electron is literally the wave,



This would imply we see 1/2 electrons



But we don't!

Probability Interpretation

- Wave represents probability of particle being at given place: more precisely

Note Electron must be somewhere: i.e. probability of detecting it somewhere = 1

Think of a die:

probability of any given face = 1/6

probability of any face being uppermost = 1

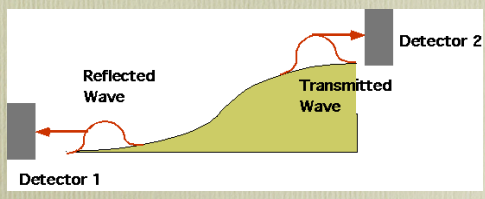
Back to barrier problem

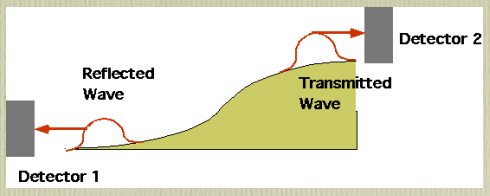
Probs must add to 1:

P_1 = prob. that electron hits detector 1:

P_2 = prob. that electron hits detector 2

$P_1 + P_2 = 1$





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

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

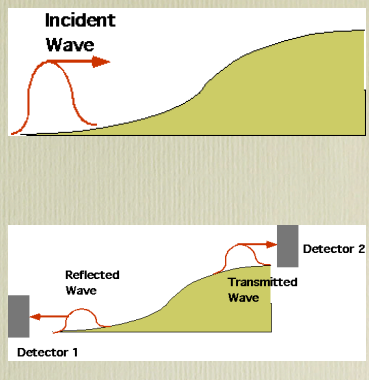
In classical mechanics, we believe that a object is the same whether we measure it or not.

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

- E.g.: suppose we measure the position of a particle 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

  God does not play dice. Einstein

  His way out was "hidden variables"

  Underneath quantum mechanics, there is some "clockwork" where everything is deterministic. It only looks random on the surface.

Schrödinger's Cat

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

- The trivial version: you have a box, with a lid: when it is opened, cyanide gas is released.

  Take a cat.

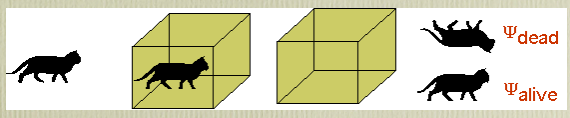
  Put it in the box and close the lid.

  Is the cat dead?

  Why don't you look?

- The sophisticated version: you have 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 its either dead or alive
- **Quantum Mechanic** It is indeterminate until you measure it . More 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.

Bell's theorem shows that there is a measurement that you can do on the polarizations of the particles which is incompatible with any possible hidden variable theory.

Aspect did the experiment.

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

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?

Conclusions:

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!

????????????

(Ugh!) Does it bother you that 20th century technology depends fundamentally on something no-one understands?