MICHIGAN STATE UNIVERSITY

SCIENCE FESTIVAL

Search...

Home About Schedule Visitors Get Involved Schools Media

Events

Featured Events

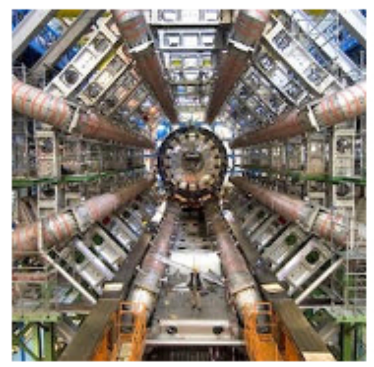
Full Schedule

Search

Nothing Ain't What It Used to Be

Featured Event

This event has been specially chosen by the Science Festival planning team! Here's what they have to say about it:



Nothing Ain't What It Used to Be

Saturday, April 8th, 12:00-12:45 PM and 2:00-2:45 PM

Biomedical and Physical Sciences Building, Room 1420

A little bit of nothing goes a long, long way since, these days, nothing is really something. In fact, our understanding of nothing has changed in just the last few years in particle physics and in cosmology.

How do we know nothing? Well, since 2010, 7,000 of us have been peering into nothing at the CERN Large Hadron Collider in Geneva, Switzerland. We dug around in spacetime and reached an important conclusion about — wait for it — nothing!

At the same time, since 1998 hundreds of astronomers have been looking deep into the cosmos and they found...nothing as well! The nothing that we found at CERN is called the Higgs Boson...that little bit of the vacuum that makes everything...something. The nothing that astronomers uncovered is called Dark Energy, possibly the bang in the Big Bang.

Nothing is a very strange place and in this presentation, we'll talk about it.

Type: Talk or Demonstration

Description:
A little bit of nothing goes a long, long way, since, these days, nothing is really something. In fact, our understanding of nothing has changed in just the last few years in particle physics and in cosmology. How do

Times and Locations

Date/Time: 4/8/2017 12:00 - 12:45 PM

Location: Biomedical and Physical Sciences Building, Room 1420
View on MSU Campus Map

Date/Time: 4/8/2017 2:00 - 2:45 PM

Location: Biomedical and Physical Sciences Building, Room 1420
View on MSU Campus Map

Ages: All Ages

Scientific Disciplines:

- Physics or Astronomy

hi

Lecture 24, 04.06.2017

Quantum Mechanics 4

housekeeping

Question about anything?

I'll make a movie for you:

Poster selection:

April 13, outline due April 20...read the instructions.

Homework:

For month of April, I've shifted due dates to Saturdays.

a problem

with my website as I've described in Facebook.

It's still unavailable from a university computer

It is available everywhere else

This week you should be reading:

The Theory of Everything, Chapters 4 and 5

Physics, Concepts & Connections, Chapter 13

Honors Project

Data due April 22. Paper due on May 4 (final day).

Read the Second of two sets of instructions:

`MinervaInstructions2_2017.pdf` in

www.pa.msu.edu/~brock/file_sharing/QSandBB/2017homework/honors_project_2017/

Quantum Mechanics, so far:

Light has both wave and particle-like properties

Bohr Model:

- electrons are in atomic orbits
- fixed in radius and energy
- electrons make transitions - spectra

Electrons have both wave and particle-like properties

- for both light and electrons, $p = \frac{h}{\lambda}$
- standing wave patterns at Bohr radii worked

Electrons are represented by imaginary wavefunctions, ψ

- the square of the wavefunctions represent the probability of finding an electron at a point at a time

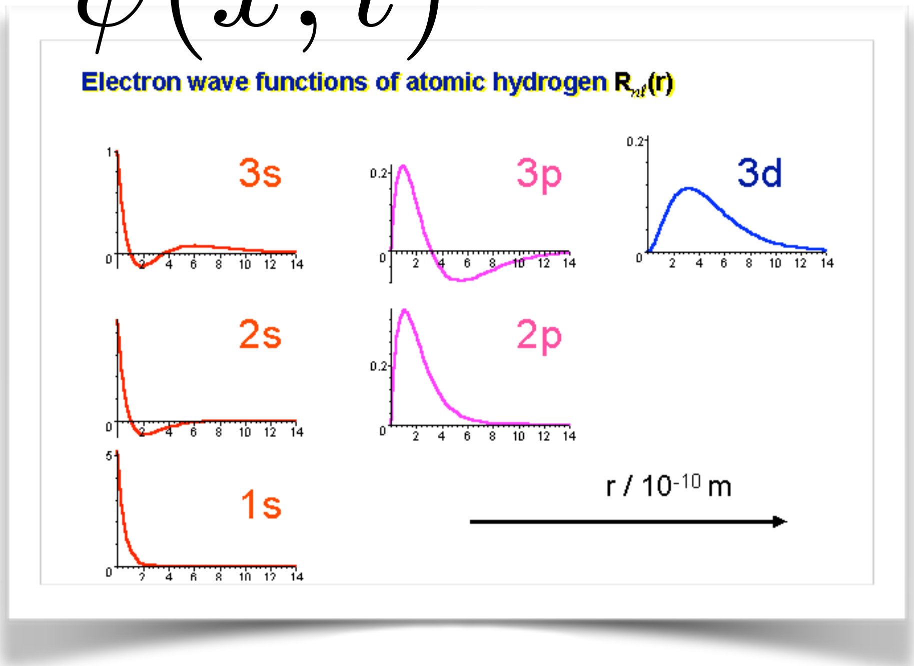
Heisenberg Uncertainty Principle:

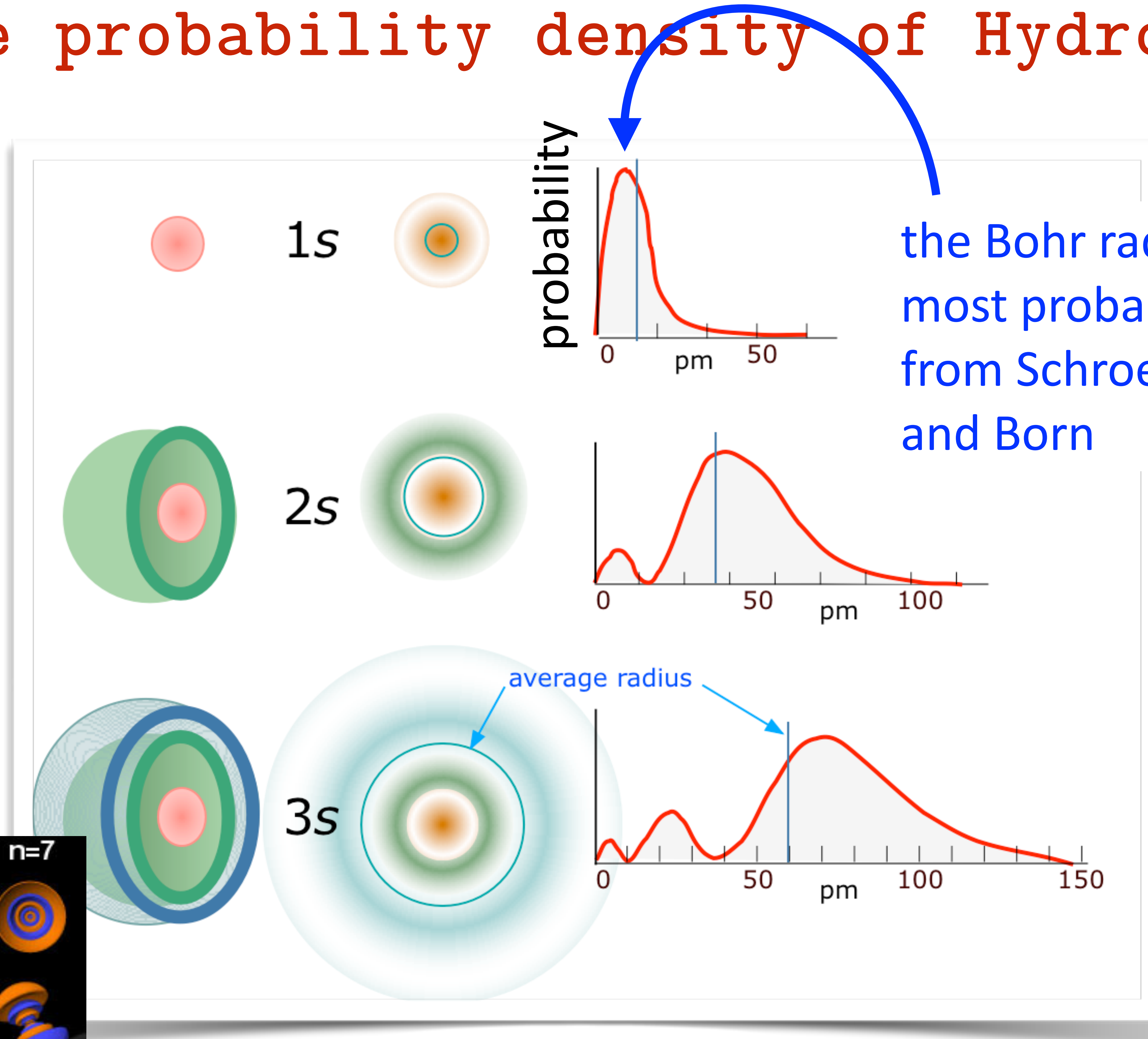
- measuring a precision location of a quantum makes momentum imprecise
- measuring a precision time interval of a quantum makes energy imprecise

slice through the probability density of Hydrogen

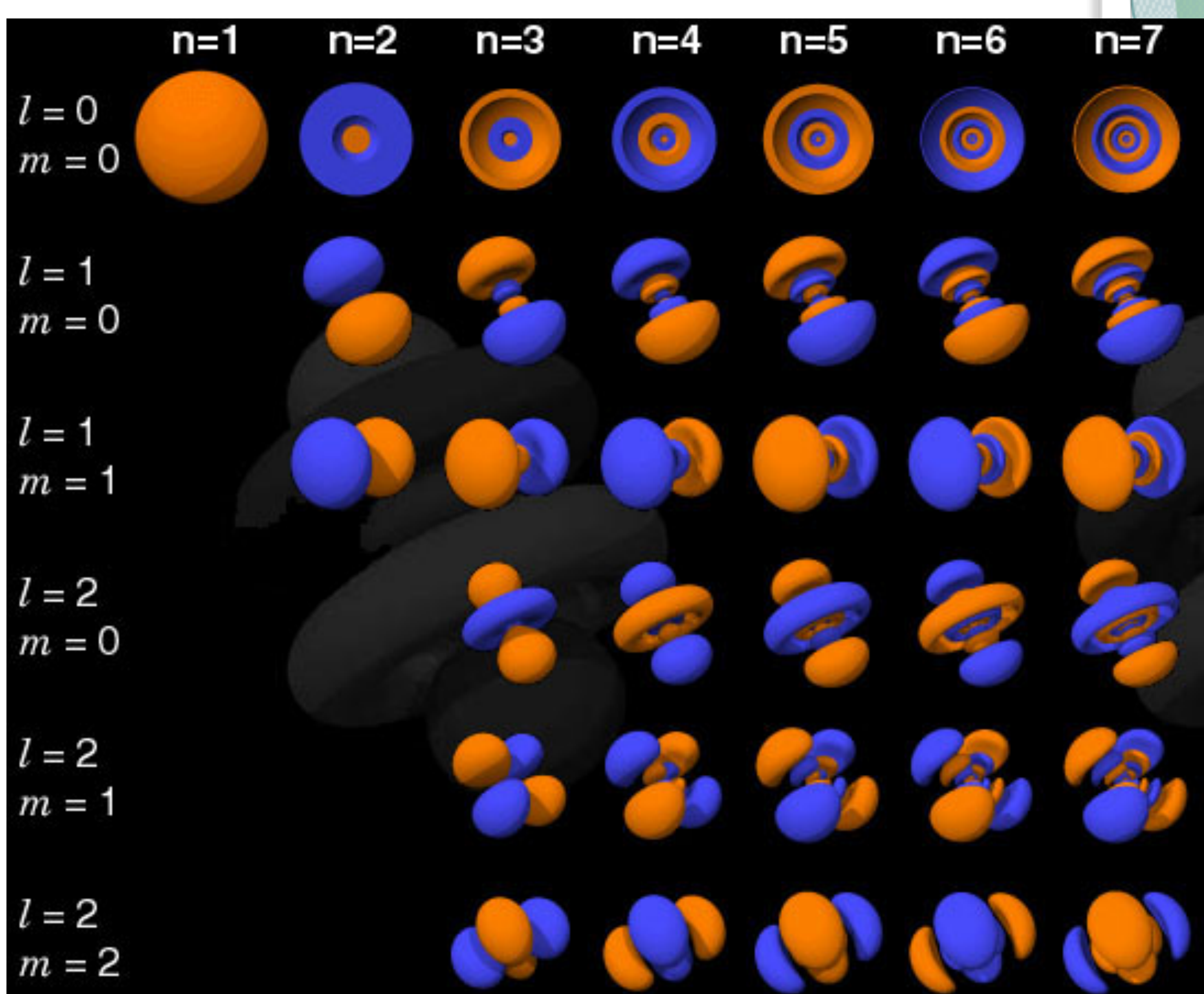
Square these:

$$\psi(x,t)$$





the Bohr radius - the most probable radius from Schroedinger and Born



`there is`

NO WAY to beat it in any of these measurement scenarios

the inverse relation between p and λ messes with you every time

$$p = \frac{h}{\lambda}$$

but here's the hard part

the inability to determine position or momentum to arbitrary precision

is not about poor instruments

It. Is. About. Nature.

relation alert:

Heisenberg Uncertainty Relation

refers to: $\Delta x \Delta p \geq h$ & $\Delta t \Delta E \geq h$

an inherent property of Nature

example: objects to not possess precise position and precise velocity at the same time.

1932
Nobel

31 years old

Nobelprize.org
The Official Web Site of the Nobel Prize

Home | A-Z Index | FAQ | Press | Contact Us

Nobel Prizes | Alfred Nobel | Educational | Video Player | Nobel Organizations | Search

Home / Nobel Prizes / Nobel Prize in Physics / The Nobel Prize in Physics 1932

- About the Nobel Prizes
- Facts and Lists
- Nobel Prize in Physics
  - All Nobel Prizes in Physics
  - Facts on the Nobel Prize in Physics
  - Prize Awarder for the Nobel Prize in Physics
  - Nomination and Selection of Physics Laureates
  - Nobel Medal for Physics
  - Articles in Physics
  - Video Interviews
  - Video Nobel Lectures
- Nobel Prize in Chemistry
- Nobel Prize in Physiology or Medicine
- Nobel Prize in Literature
- Nobel Peace Prize
- Prize in Economic Sciences
- Nobel Laureates Have Their Say
- Nobel Prize Award Ceremonies
- Nomination and Selection of Nobel Laureates

Printer Friendly | Share | Tell a Friend | Comments

1901 — 2012 — 1932

Sort and list Nobel Prizes and Nobel Laur | Prize category: Physics

The Nobel Prize in Physics 1932
Werner Heisenberg

The Nobel Prize in Physics 1932

Werner Heisenberg

Werner Karl Heisenberg

The Nobel Prize in Physics 1932 was awarded to Werner Heisenberg *"for the creation of quantum mechanics, the application of which has, inter alia, led to the discovery of the allotropic forms of hydrogen"*.

Werner Heisenberg received his Nobel Prize one year later, in 1933. During the selection process in 1932, the Nobel Committee for Physics decided that none of the year's nominations met the criteria as outlined in the will of Alfred Nobel. According to the Nobel Foundation's statutes, the Nobel Prize can in such a case be reserved until the following year, and this statute was then applied. Werner Heisenberg therefore received his Nobel Prize for 1932 one year later, in 1933.

Photos: Copyright © The Nobel Foundation

TO CITE THIS PAGE:
MLA style: "The Nobel Prize in Physics 1932". Nobelprize.org. 14 Mar 2013
http://www.nobelprize.org/nobel_prizes/physics/laureates/1932/

Policy | Terms of Use | Technical Support | Copyright © Nobel Media AB 2013

Home | A-Z Index | FAQ | Press | Contact Us

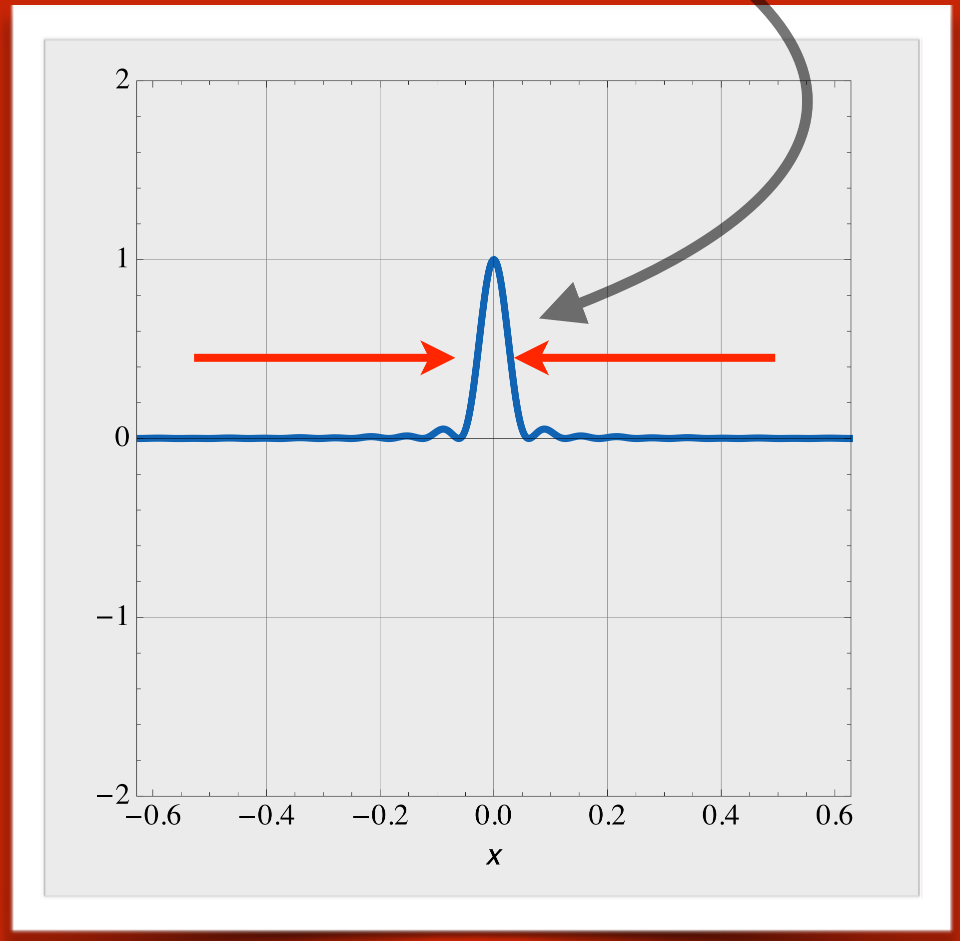
a classical particle (dot) and its wavefunction

the wave combinations localize the state...with some spread in x

waves of different wavelengths?

$$p = \frac{h}{\lambda}$$

different momenta



Heisenberg Uncertainty Relation at work again

called "wavepackets"

all of the wave combinations means all of the momenta contribute: an spread in p.

The Schroedinger Equation is precisely, predictive

There is no ambiguity in how the quantum field evolves

the only measurable is its probabilistic feature…

Is the quantum field function - the wavefunction - real?

I don't know. It cannot be observed…so moot.

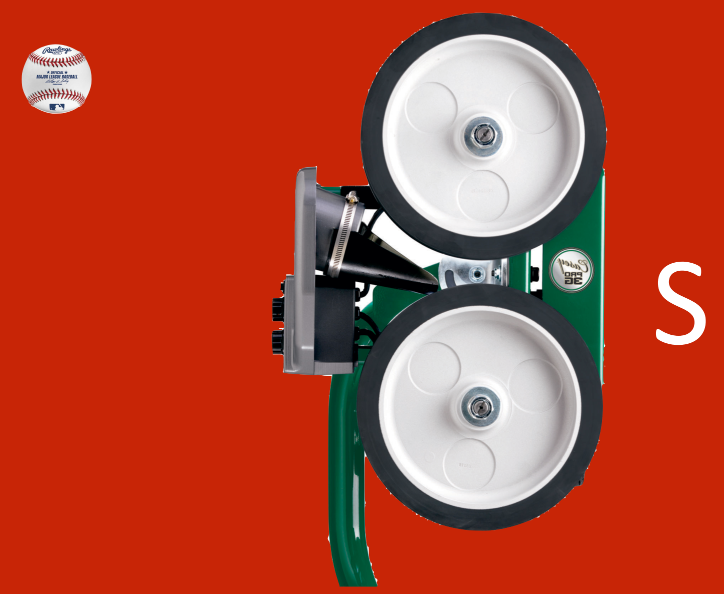
Does it work as a description of Nature?

absolutely…to exquisite precision

Nature’s little joke

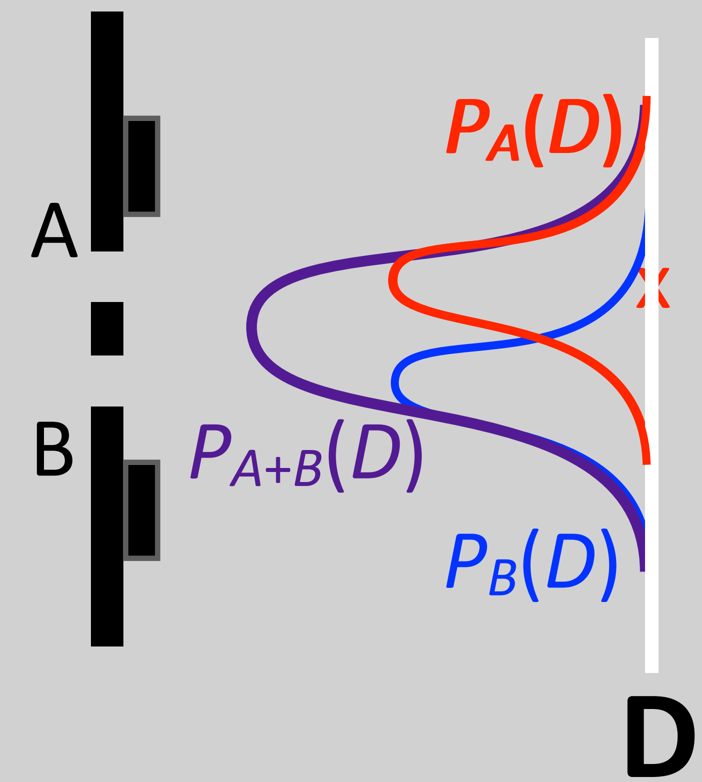
is encapsulated in a famous Feynman-description

a Gedankenexperiment...



two slit experiment

2 + 1 ways

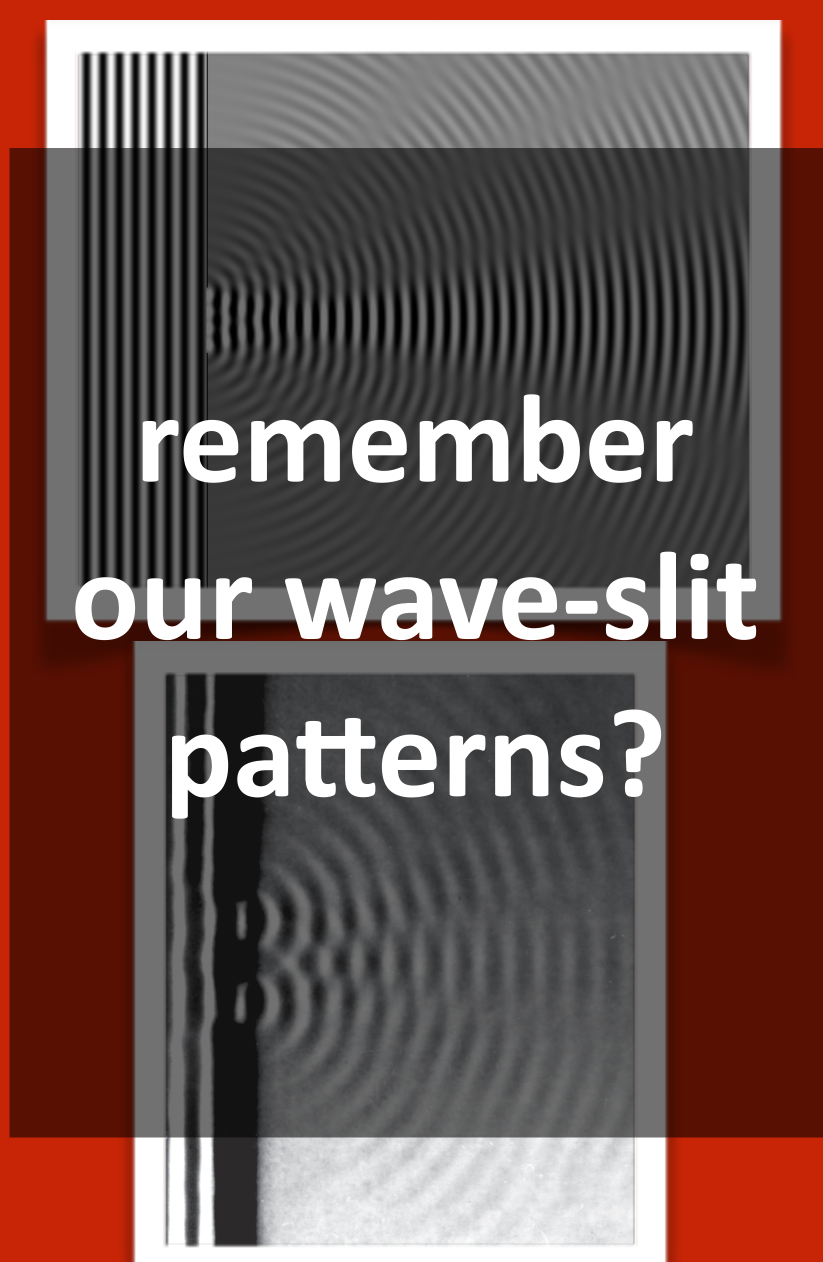


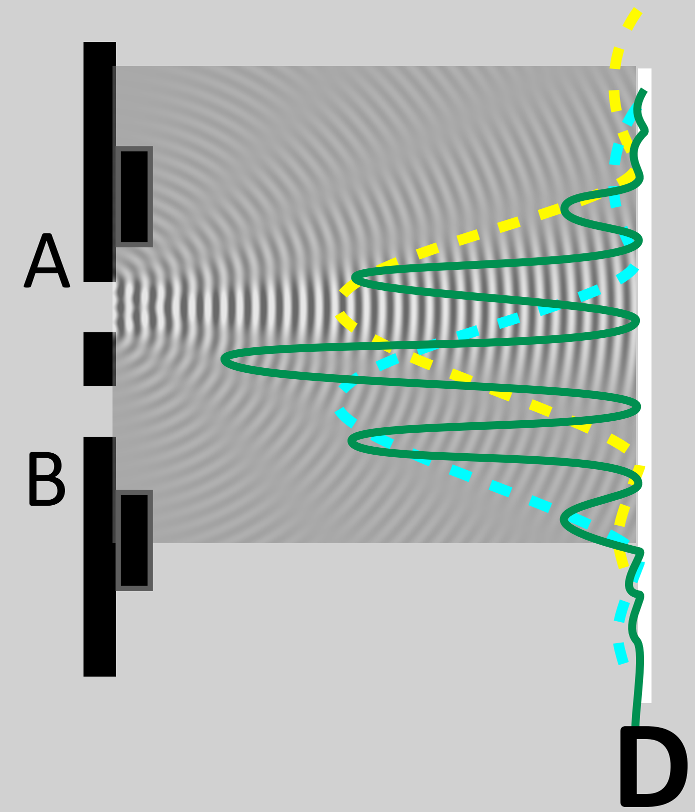
Two slit experiment with classical baseballs

$$P_A(D) + P_B(D) = P_{A+B}(D)$$

Like the “classical” situation of asking what is the probability of getting heads or tails in a coin flip...you’d add 0.5 and 0.5.

S

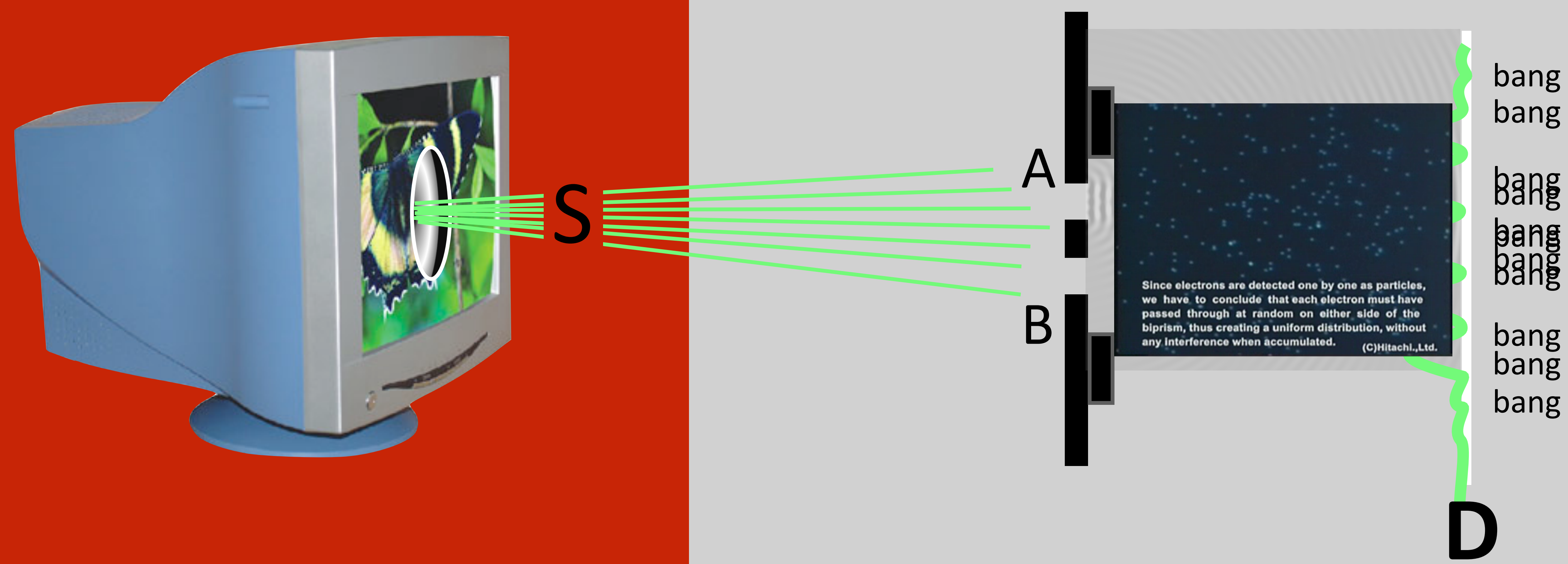




Two slit experiment with waves

$$P_A(D) + P_B(D) \neq P_{A+B}(D)$$

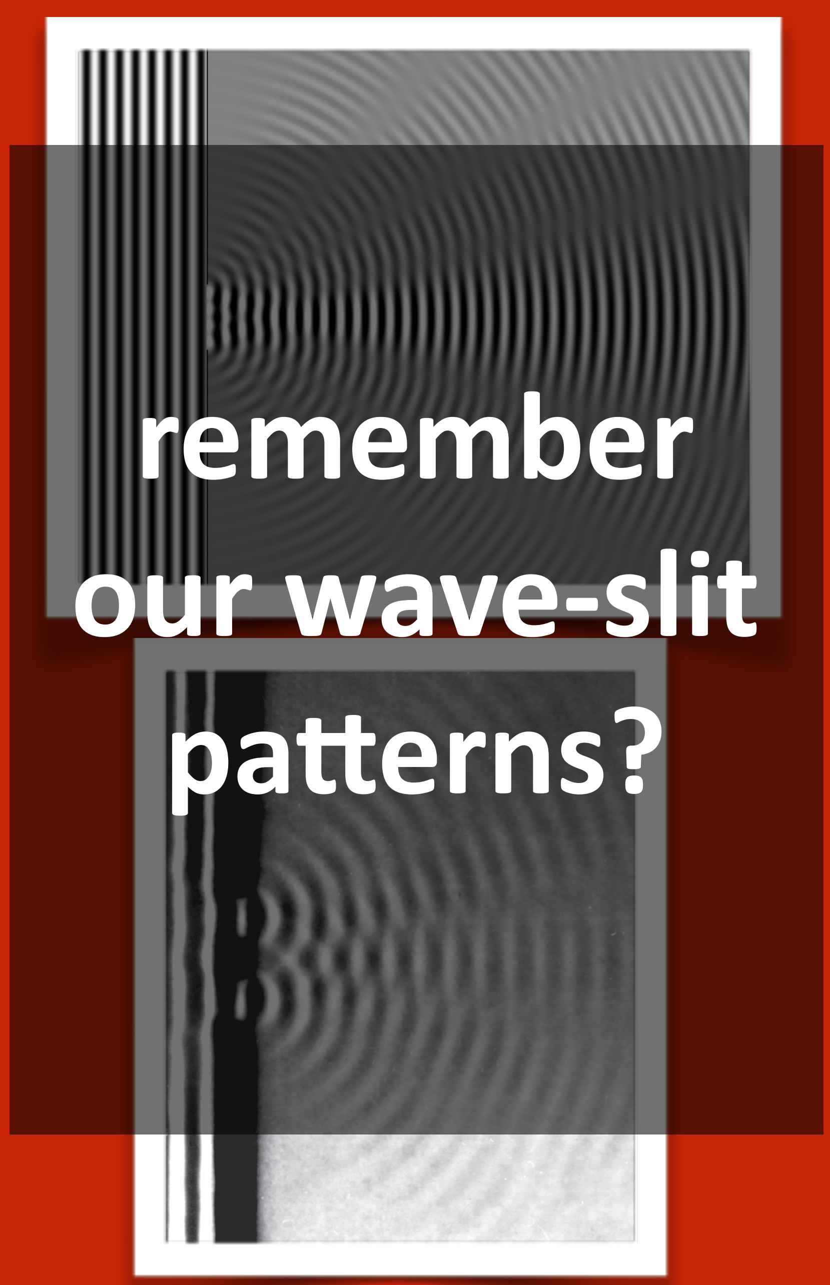
Interference causes the characteristic diffraction pattern



Two slit experiment with **electrons?**

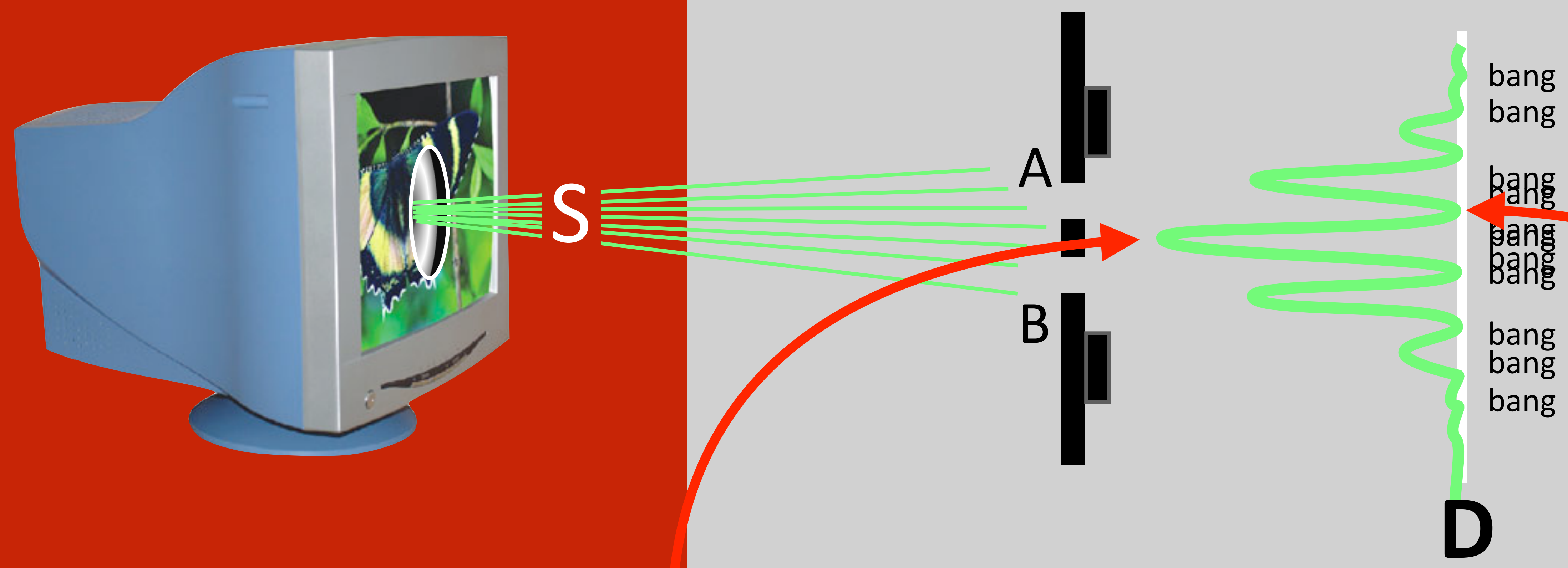
$$P_A(D) + P_B(D) \neq P_{A+B}(D)$$

Interference causes the characteristic diffraction pattern



Same result as for waves.

Maybe not a surprise given what's come before, eh?



probabilities don't add

it's the **quantum fields** that do the wavy-ness!

$$P_A(D) + P_B(D) \neq P_{A+B}(D)$$

$$P_D = |\psi_A + \psi_B|^2$$

$$P_D = \psi_A^2 + \psi_A^2 + \psi_A \psi_A^*$$

at some points this can be negative, sometimes positive

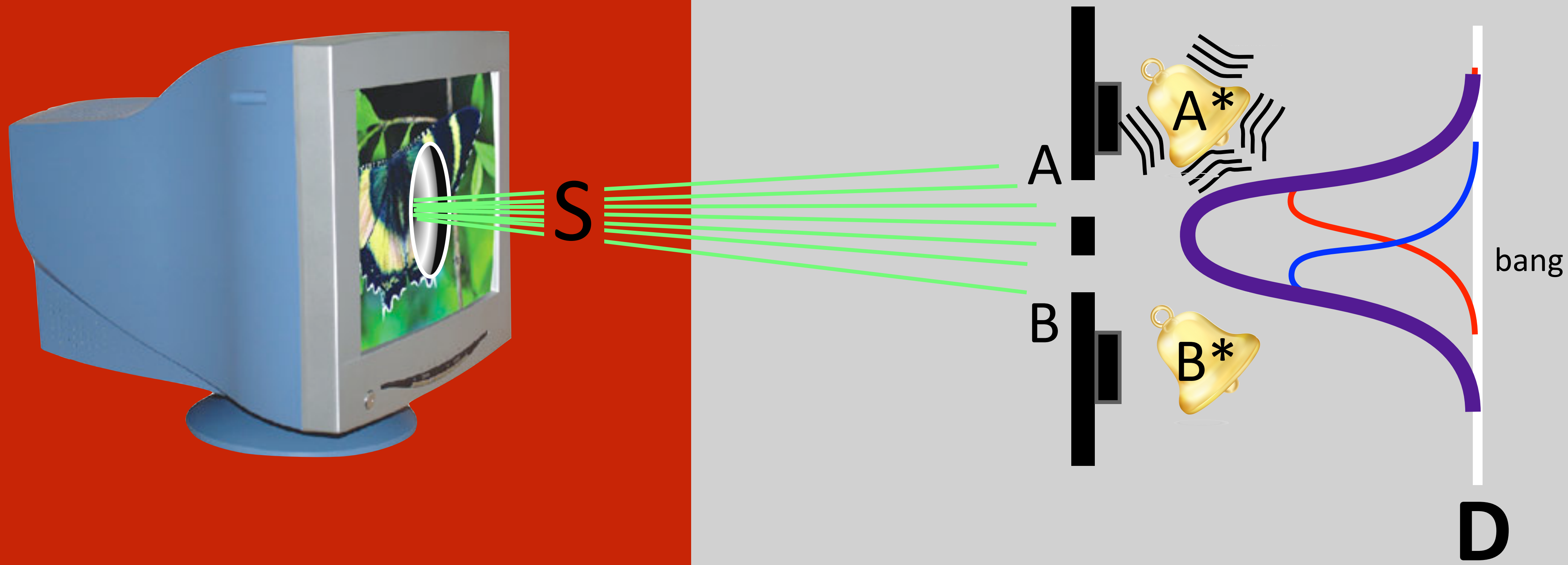
$$\psi$$

which gap did any electron come through?

okay…let’s trick it

rig an alarm that sounds when an electron goes through a slit.

Hah!



Two slit experiment with electrons and an alarm?

So the sequence “S-A-A*-D occurred.

Every time A* rings - red curve. B* rings, blue curve.

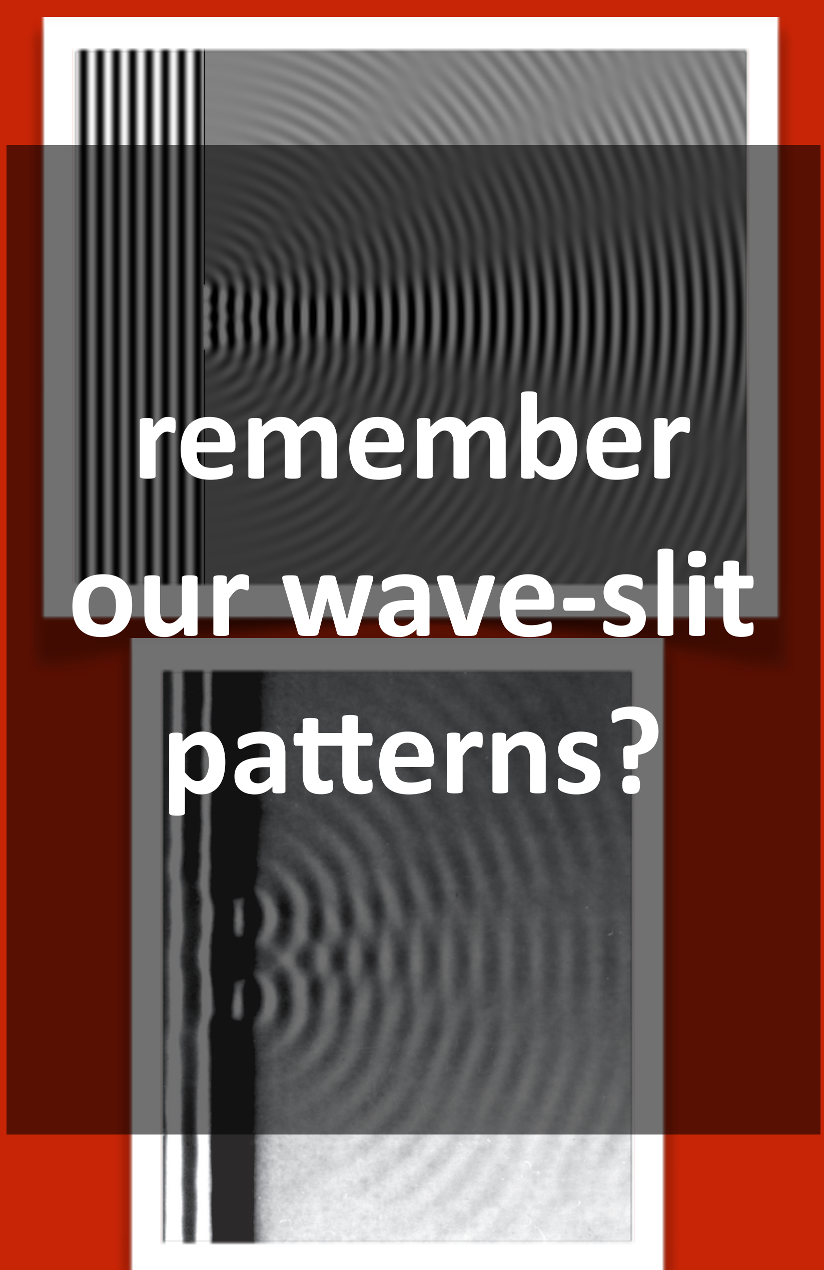
Same result as for baseballs.

Interference has gone away!!

Now: A* is a DISTINGUISHABLE event from B*

We specified the path...

and that changed the reality.



summarize

the classical situations

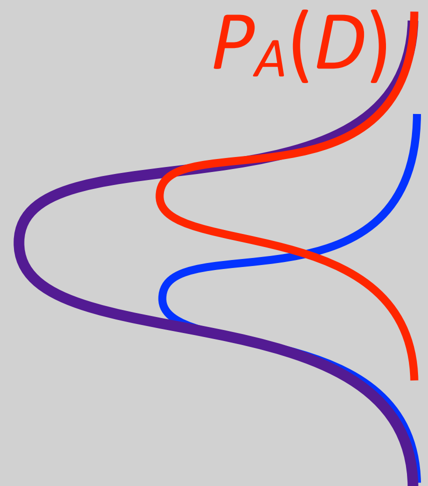
For **macroscopic objects**: outcomes add “normally”:

The result of

whatgoesthroughA and whatgoesthroughB is

the sum of whatgoesthrough(A **or** B)

one or the other



For **waves**: outcomes interfere:

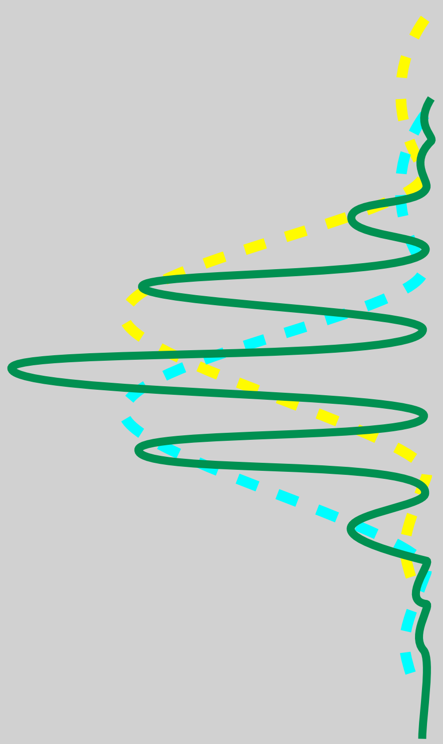
the result of

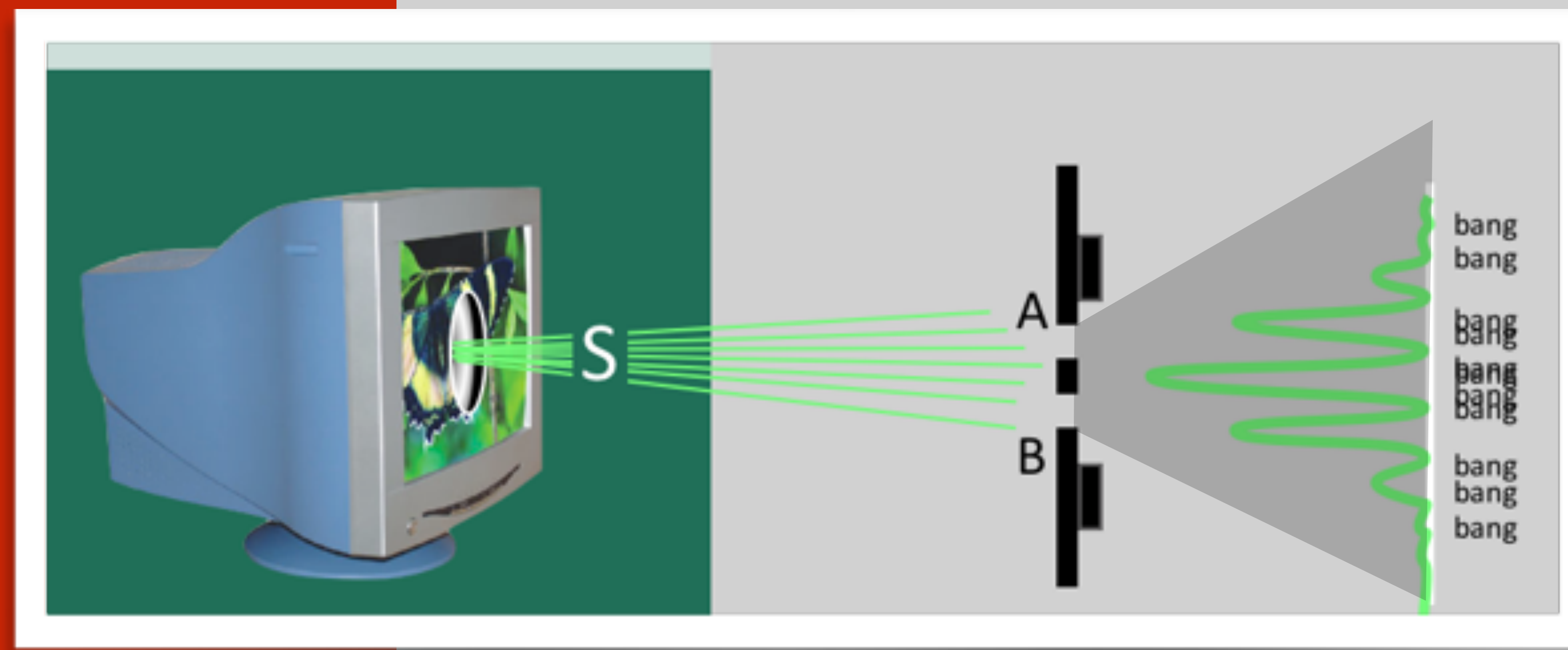
whatgoesthroughA and whatgoesthroughB is

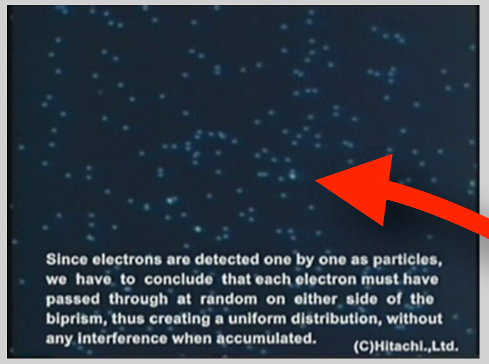
the interference of whatgoesthrough(A **and** B)

both at the same time

the waves interfere







where is the electron

it's real only when you make a measurement

and your measurement can determine how it's real

The electron is real at the screen.
it's unambiguously...there.
the "bang" is a measurement

what about here?

We have to say that an electron:

- goes through both slits
- and is in a "superposition" state,
  *here of **both** the state* ψ_A *and the state* ψ_B

As soon as measurement is made...the superposition goes away and the potentiality becomes the actuality...according to the probabilistic prediction of the Schroedinger Equation.

what we can say is real

is now very tricky

and not understood.

We know that quantum fields contain all of their potentialities

and a measurement "collapses" them into just one outcome

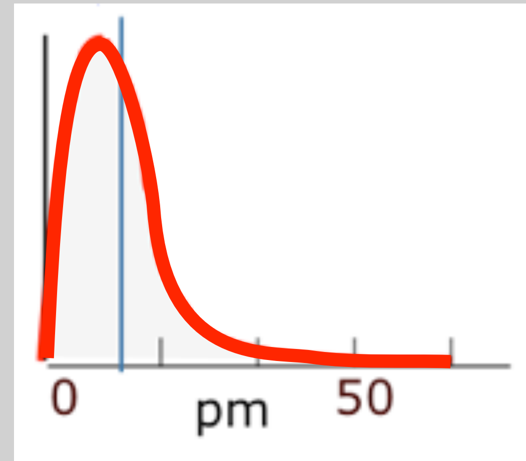
the concept of a "measurement" is totally not understood.

the wavefunctions are everywhere

spread out and overlapping

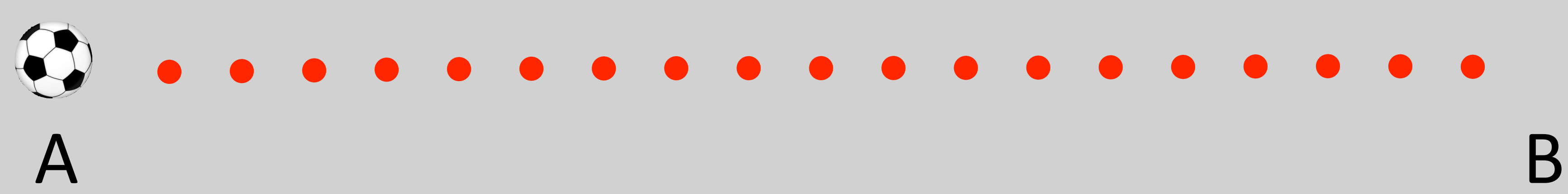
that's how molecules stay together

but...jeez. everywhere.



doesn't go to zero.

There's a probability that the electron in one of your water molecules might spend a brief time at the Louvre



Something big...seems to have a definite trajectory

Something tiny...doesn't.

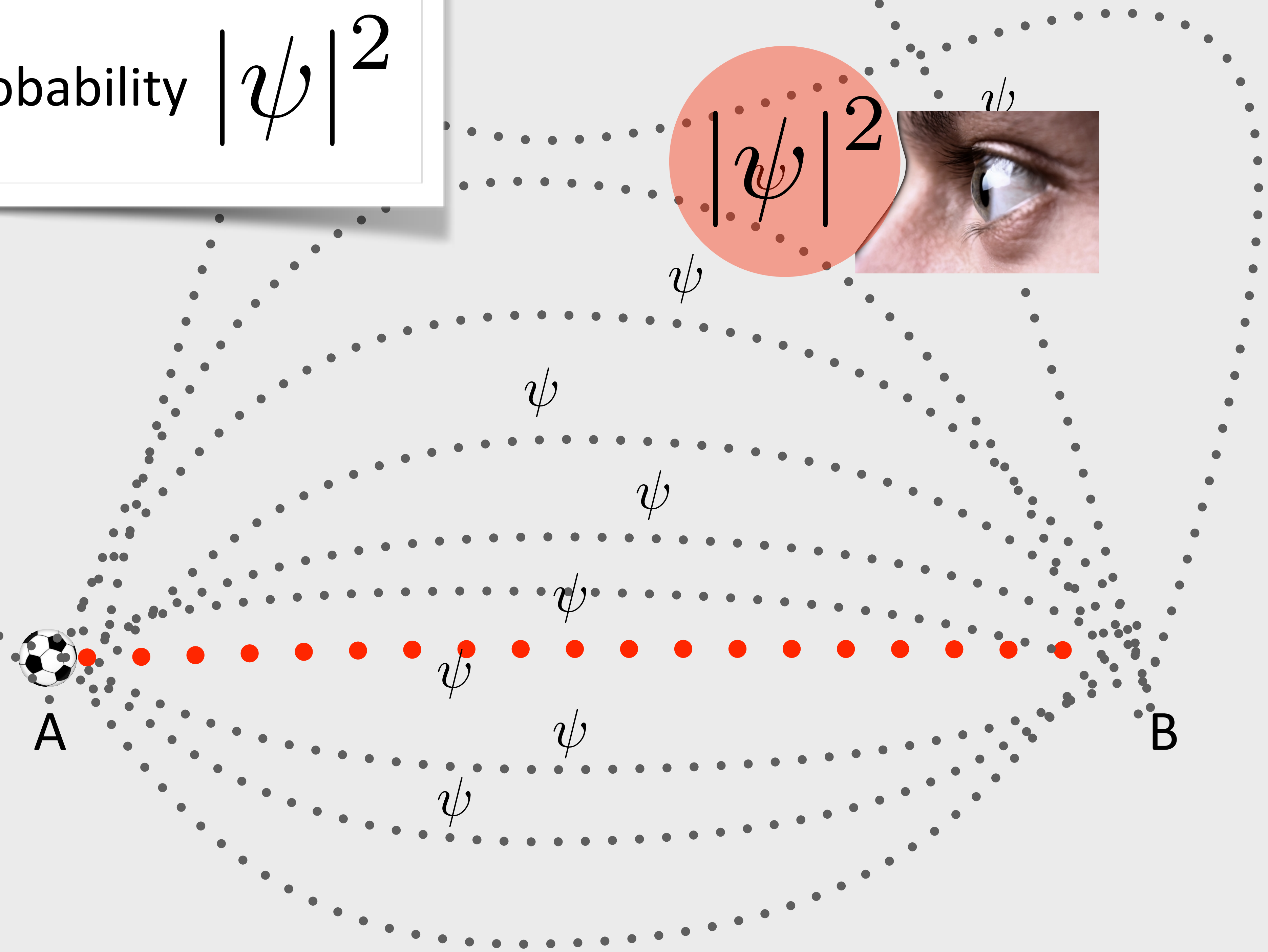
the wavefunctions are everywhere

They're waves, after all.

make a measurement....there

Only then is it real.

the electron is there with probability $|\psi|^2$



Feynman's picture was one of particles: which take all possible paths

We can calculate the wavefunction at any point, very precisely...it's completely deterministic

The trajectory of a big object?

Overwhelmingly probable quantum likelihood: the classical path

so where is a quantum

before it's measured?

anywhere? everywhere?

yeah.

to take it to an absurd conclusion: the dreaded Schroedinger's Cat

proposed by Schroedinger as an absurdity

because he too had become disgusted with this own creation - he switched to biology!

Schroedinger must have been a dog person

Imagine:

a radioactive source,

Geiger counter, and

a glass bottle of a deadly poison

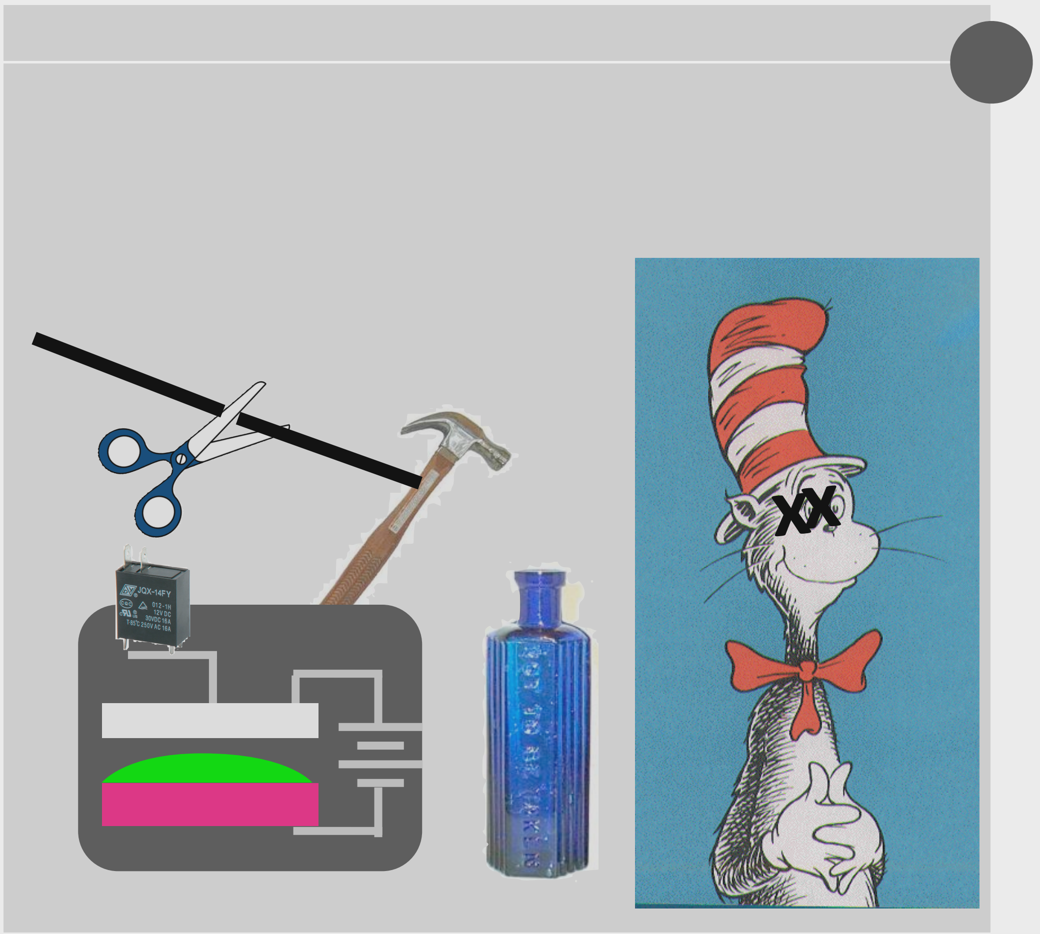
with a cat

in a box,

a weight drops on the glass, breaking it

after the first radioactive decay?

...dead cat.



Schroedinger must have been a dog person

Now imagine that the radioactive nucleus as a **half life of 10 sec**.

so, after 10 s,

50-50 chance that it has decayed

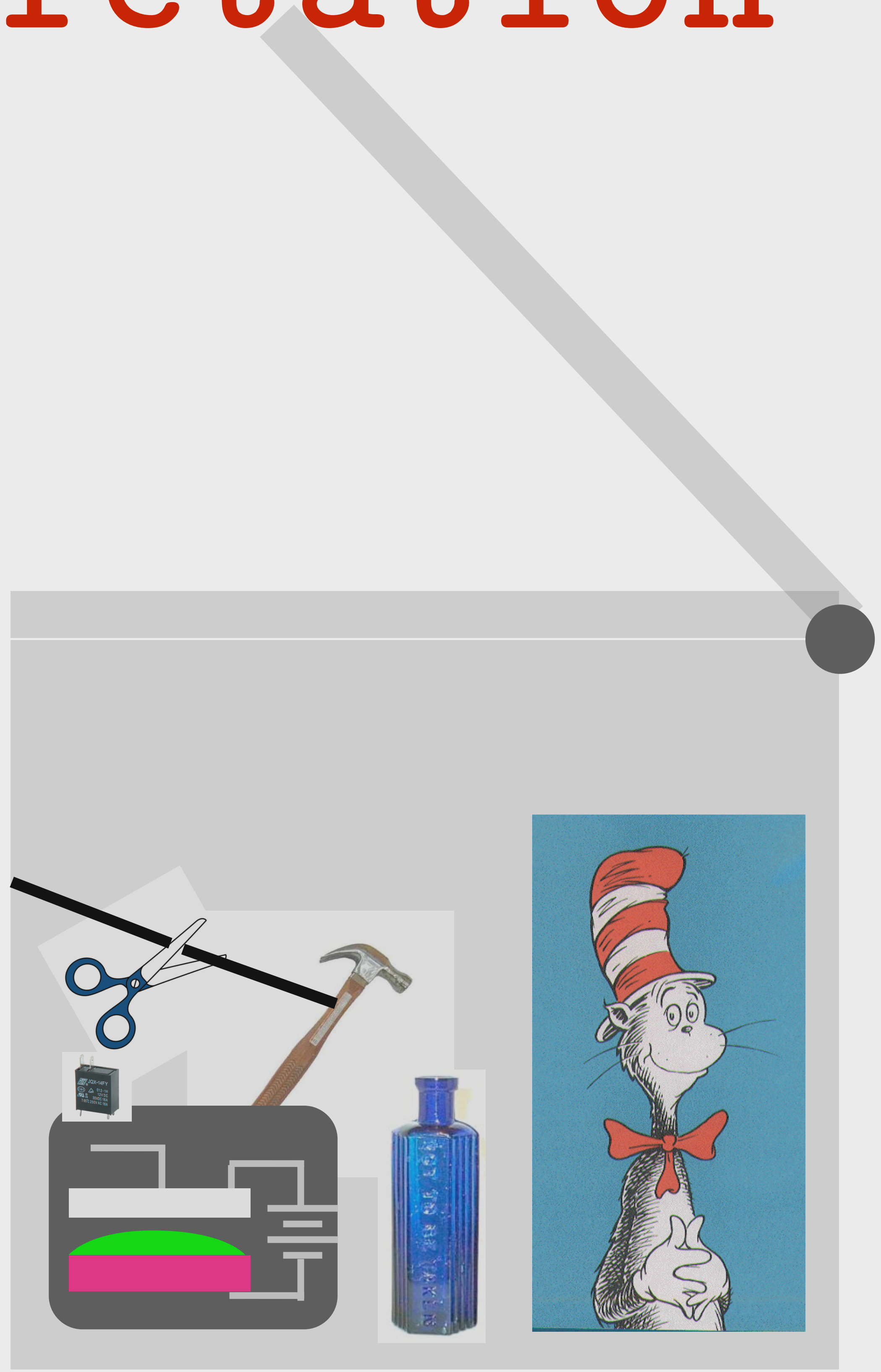
Set it all up...wait for 10 seconds.

what is the state of the cat?

alive or dead?

or both?

‘‘Copenhagen Interpretation’’



It is meaningless

to speak of reality without a measurement

Entities have no definite reality

the cat is neither alive nor dead

or it is both

To know you must open the box

make a measurement

this is how we have to think about it:

before measurement: alive-dead state -
superposition state of both

after measurement: is **either** alive **or** dead

here's our house

just before painting
last year

need to pick a color:

my wife says "red"

I say "blue"

SHERWIN-WILLIAMS.
quantum paint

I expect it to be:

purple

mixing red and blue

but the quantum mechanical paint

that I paid extra for?

can't "exist" in a superposition, mixed state.

Only one state.

sometimes it's red

but the quantum mechanical paint

that I paid extra for?

sometimes it's blue

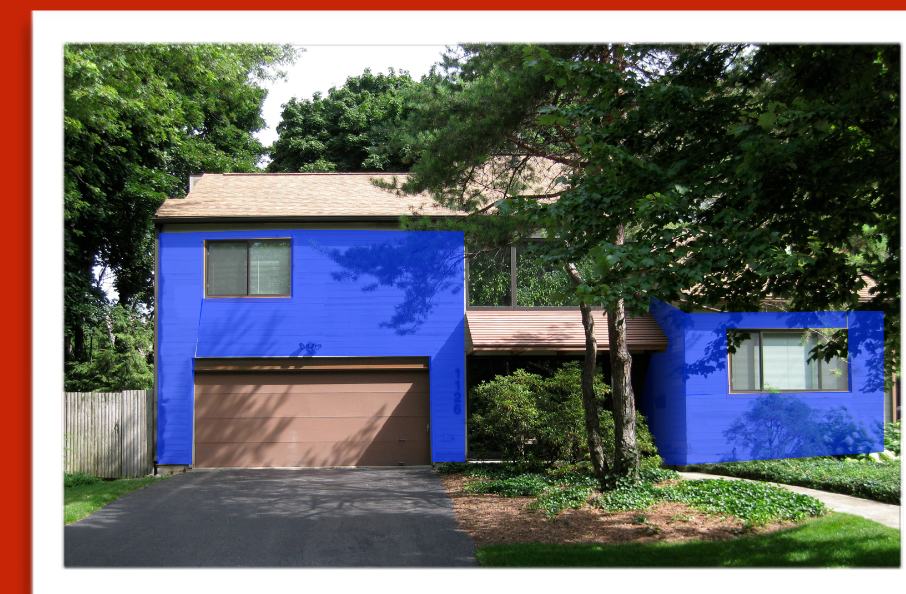
it’s never the mixture

that it potentially might be

one or the other

More red paint?

not redder…just red more often



the cat is either alive or dead,
not both.

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

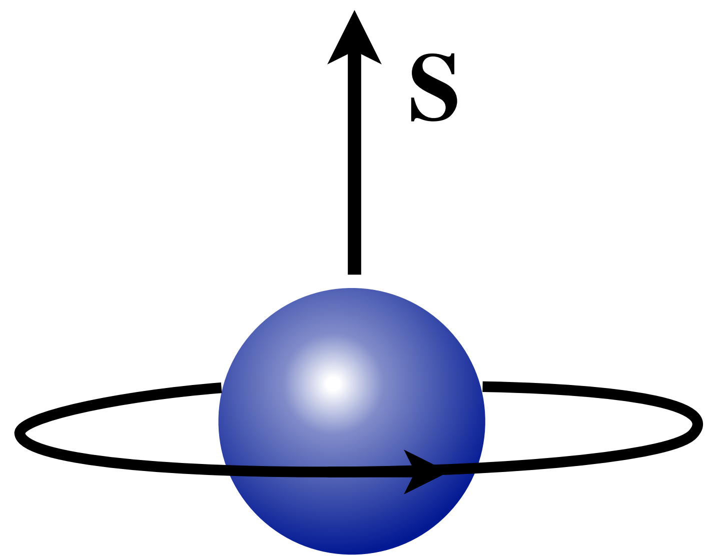
But we can calculate with Quantum Mechanics very, very well.

We're all highly skilled Quantum *Mechanics*

electrons are little magnets

They behave in a magnetic field as if they are little spinning current spheres

The electron **itself** is *like* a spinning charge...



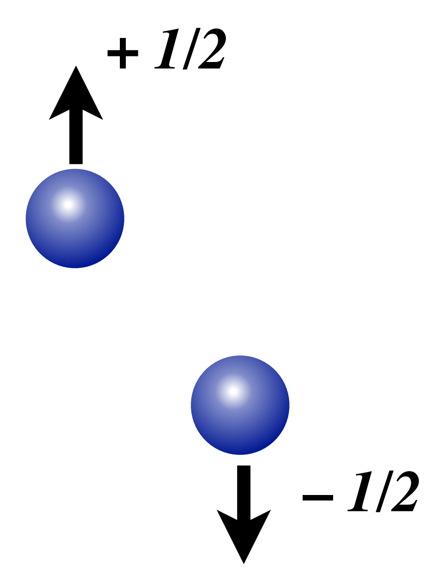
Electrons have an **intrinsic** angular momentum, “S”: “spin”

$$S_z = m_s \frac{h}{2\pi}$$

But, the “spin” can only take on two values:

$$m_s = +\frac{1}{2} \quad \text{or} \quad m_s = -\frac{1}{2}$$

We say
“spin, plus 1/2” or “spin up”
and
“spin, minus 1/2” or “spin down”



The electron is NOT

a ball of spinning charge

its outer edges would have to move >> c

This is a quantum mechanical feature with no classical analog

Pauli Exclusion Principle:

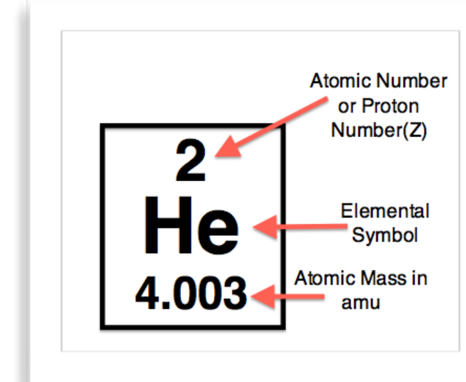
No two electrons can be in the same quantum state

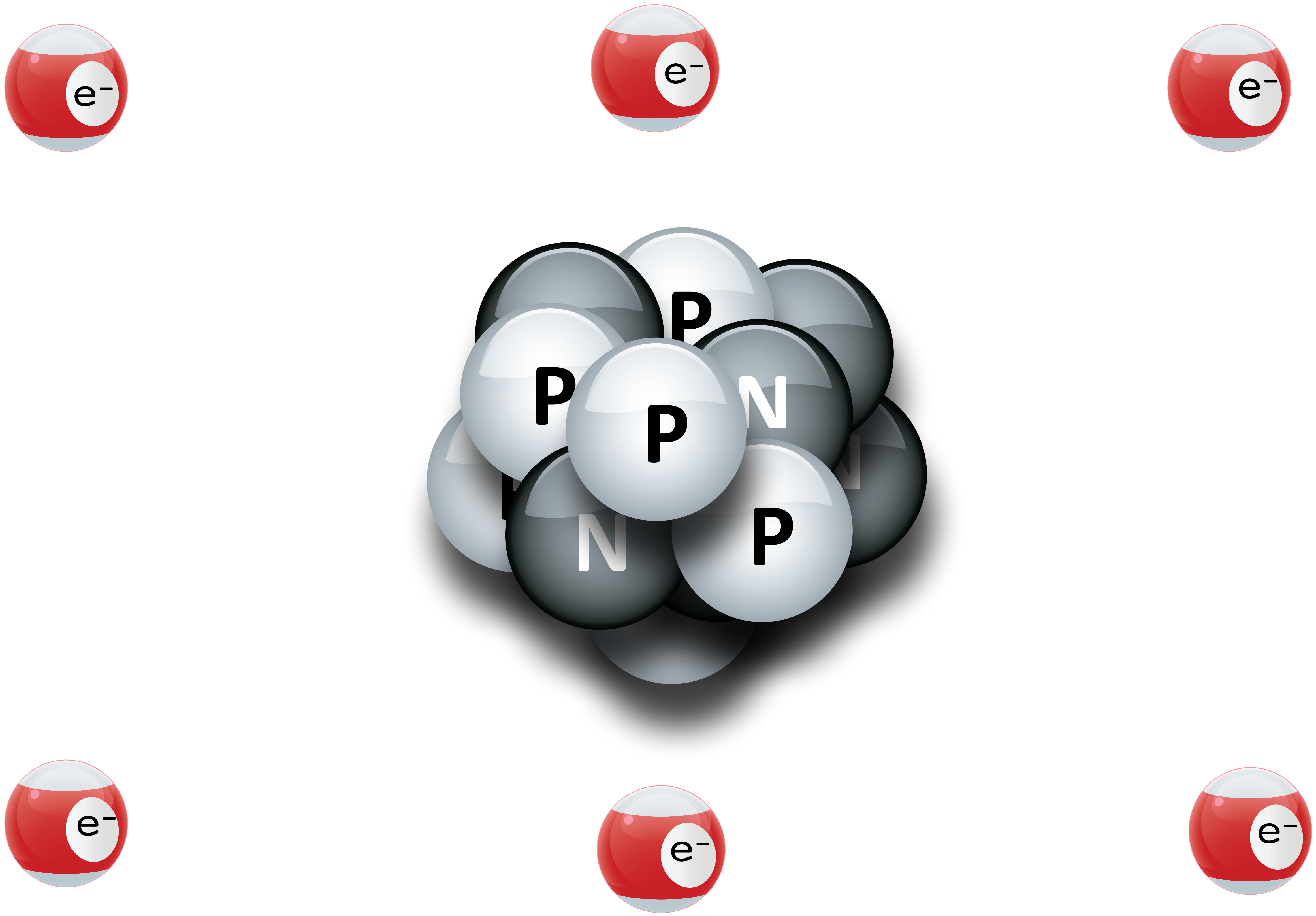
that is, have identical “quantum numbers”

...integers that characterize the atom

Carbon... 6 electrons, 6 protons, 6 neutrons:

$$^{12}_{6}C$$



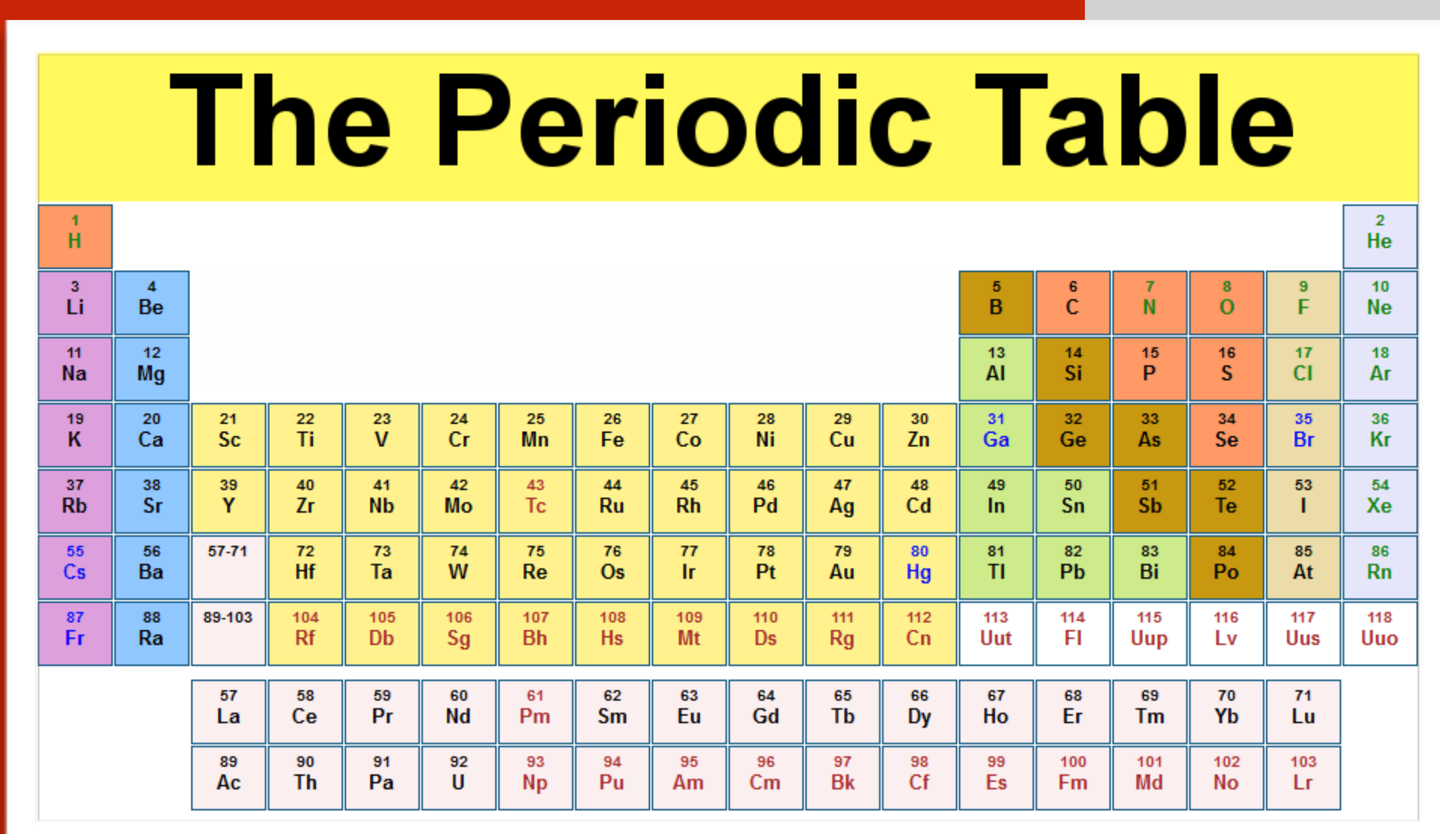


The Pauli Exclusion Principle

Explains it

& SPIN is the reason

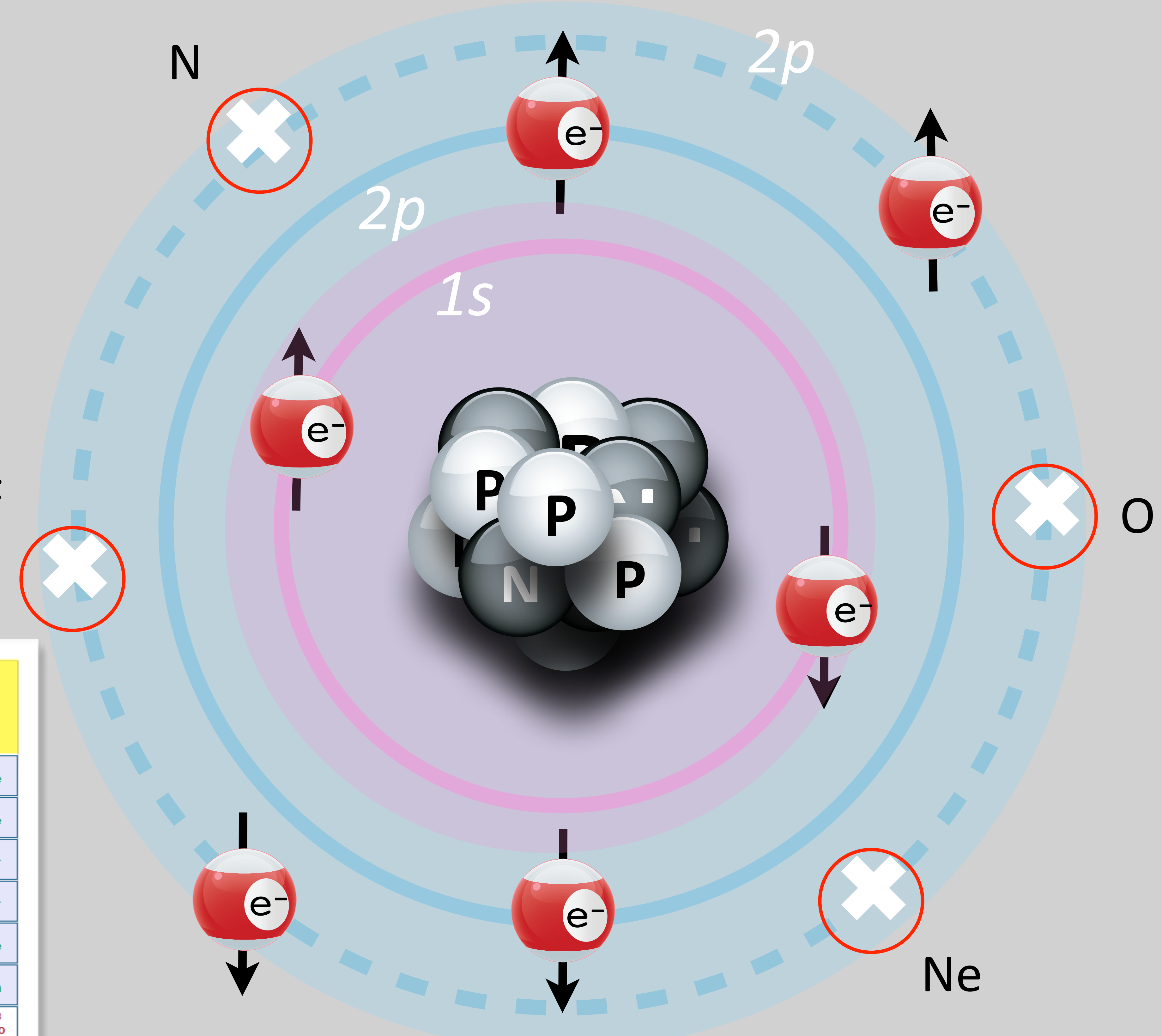
"1s2 2p2 2p6 3s2 3p6..."



How come Carbon *is* like:

The Pauli Exclusion Principle still works

...since **spin up ≠ spin down, so different quantum states**



The combination of Schroedinger, Pauli, Uhlenbeck and Goudsmit - explained the Periodic Table jargon alert: **fermion**

refers to:	any particle with half-integer spin
entomology:	from Fermi's theoretical work on the behavior of large numbers of Fermions
example:	electron, proton, neutron

jargon alert: **boson**

refers to:	any quantum object with integer spin
entomology:	from Satyendra Nath Bose, who worked on the effects of multiple boson aggregates
example:	photon, pion, Higgs Boson

spin is a defining quality of an electron

electron

symbol: e

charge: $-1e$

mass: $m_e = 9.0 \times 10^{-31}$ kg ~ 0.0005 p

spin: 1/2

category: fermion, lepton

particle: **proton**

symbol:	p
charge:	$+1e$
mass:	$m_p = 1.6726 \times 10^{-27}$ kg = 1 p
spin:	1/2
category:	fermion, hadron

again, an inherent angular momentum and a defining property of photons

particle: **photon**

symbol: γ

charge: 0

mass: $m_\gamma = 0$

spin: 1

category: boson, aka Intermediate Vector Boson

shifting gears

antimatter

here’s a number:

0

0

zero

the # of successfully combined models of

Quantum Mechanics and Relativity

prior to 1928

remember the relativistic energy relationship

and compare it to the non-relativistic one

Classical

$$E = \frac{1}{2}mv^2$$

$$p = mv$$

$$v = \frac{p}{m}$$

Relativistic

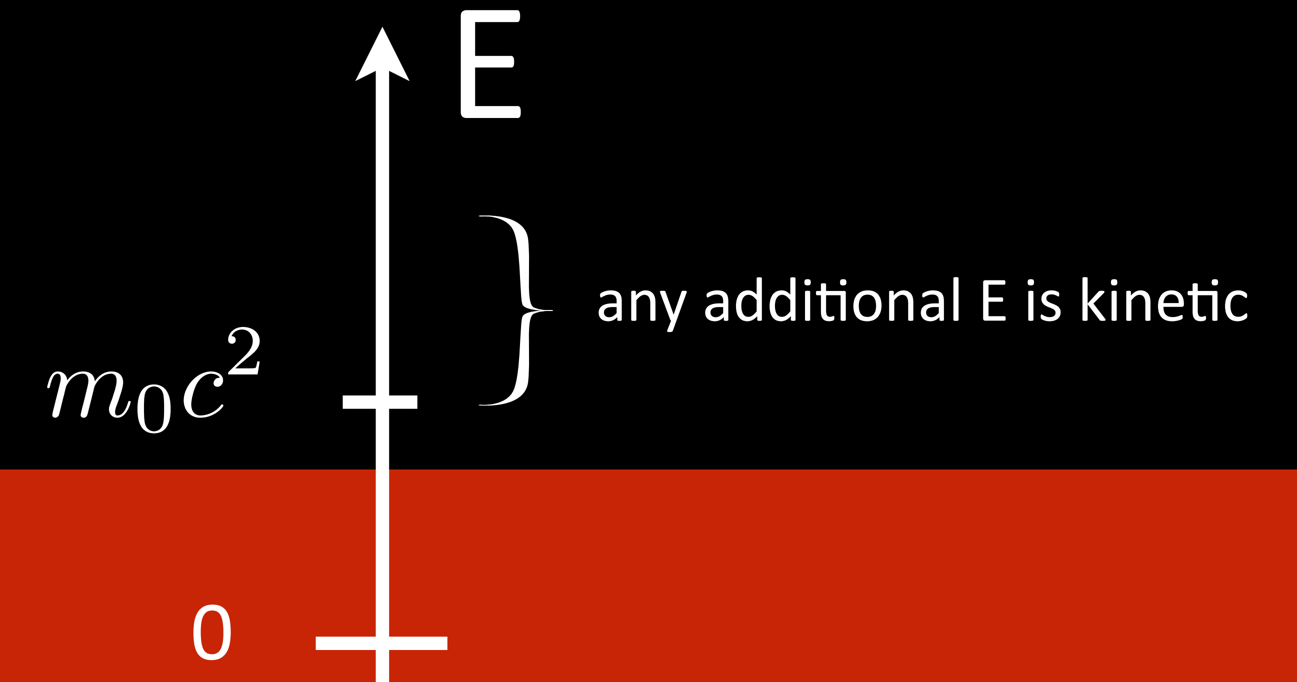
$$E^2 = (m_0c^2)^2 + (pc)^2$$

that square is problematic since it suggests:

$$E = \pm\sqrt{(m_0c^2)^2 + (pc)^2}$$

translated to Schroedinger QM:

negative energies for freely moving electrons



negative energies for unbound systems

a disaster

negative energies for unbound systems

a disaster

negative energies for unbound systems

a disaster

there's no bottom!

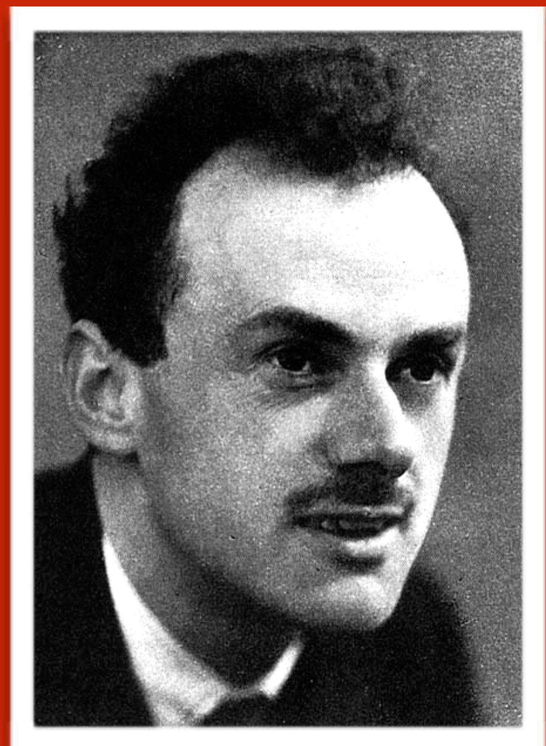
worse!

Quantum Mechanics using Relativity:

required not only negative energies

negative probabilities!

1928



Paul Dirac

1902 – 1984

> At the question period after a Dirac lecture at the University of Toronto, somebody in the audience remarked: "Professor Dirac, I do not understand how you derived the formula on the top left side of the blackboard."
> "This is not a question," snapped Dirac, "it is a statement."

hilarious interview with the Wisconsin State Journal from 1929 on the blog.

Dirac’s Mathematical Imagination

Dirac embraced the negative energy

Solved the negative probability

Dirac set out to find an equation that would solve both problems

Dirac’s imagination

negative
electric charge
+ Energy

positive
electric charge
– Energy

The “Dirac Equation” is the correct equation for electrons: Probabilities turn out okay, but required interpretation of negative energies

Dirac's result

required: 4 quantum fields, rather than 1 $\psi_{up}(+E), \psi_{down}(+E)$

2 have positive energy, 2 have negative energy $\psi_{up}(-E), \psi_{down}(-E)$

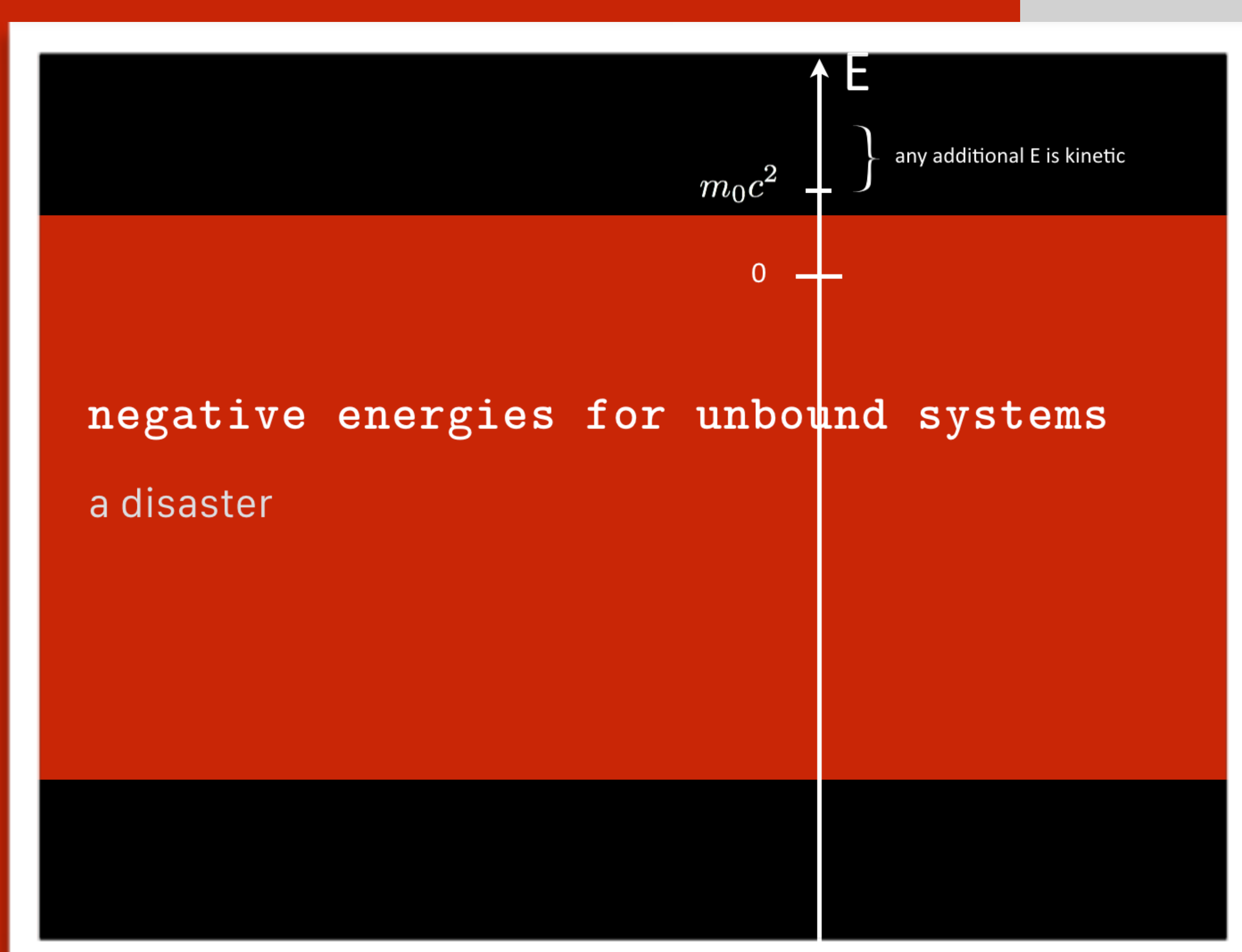
each pair is related precisely to spin

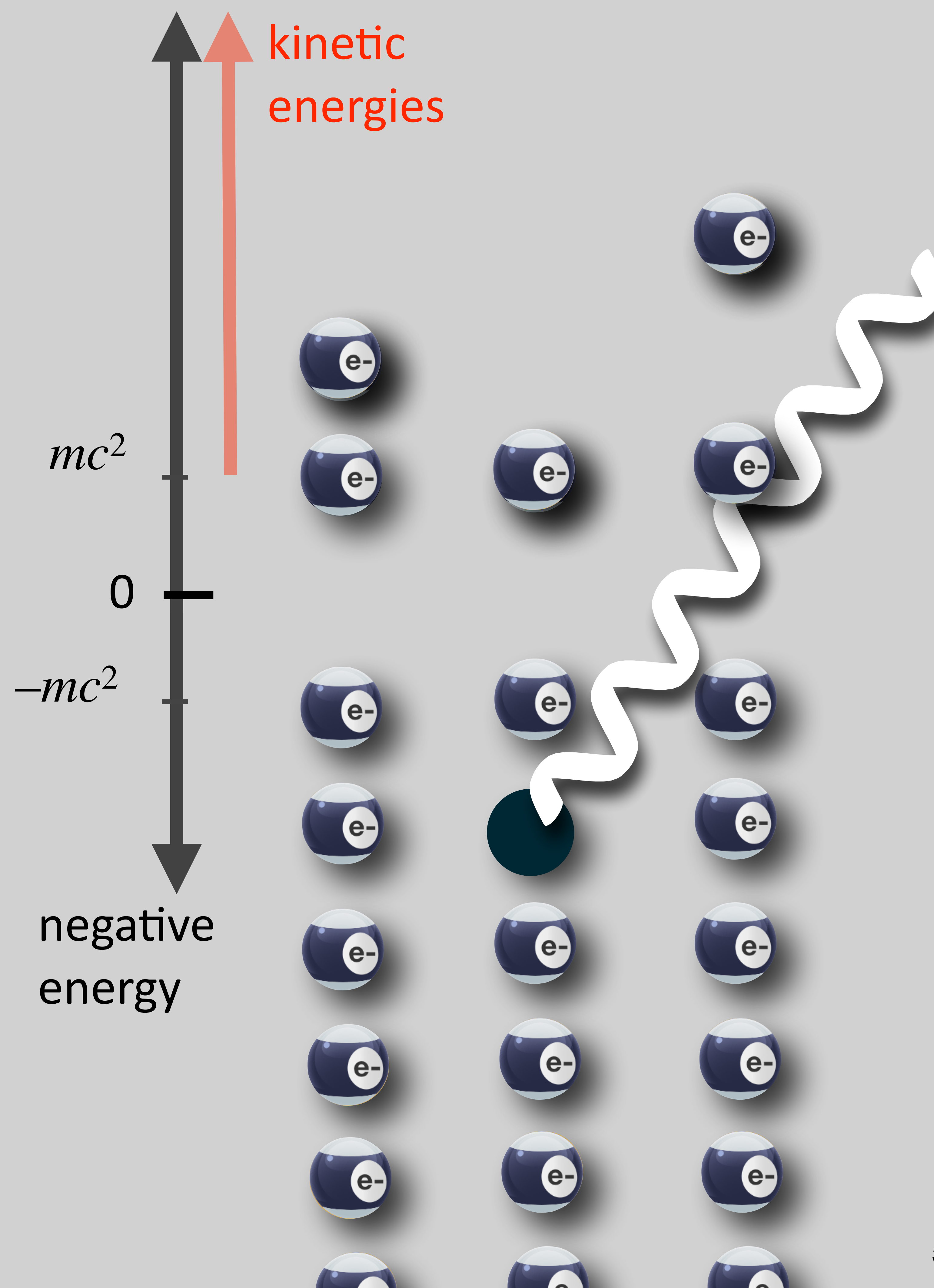
Dirac showed that spin is a wholly relativistic effect
...it just popped out of his equation.

still negative energies?

"solved" it with Pauli's Exclusion Principle

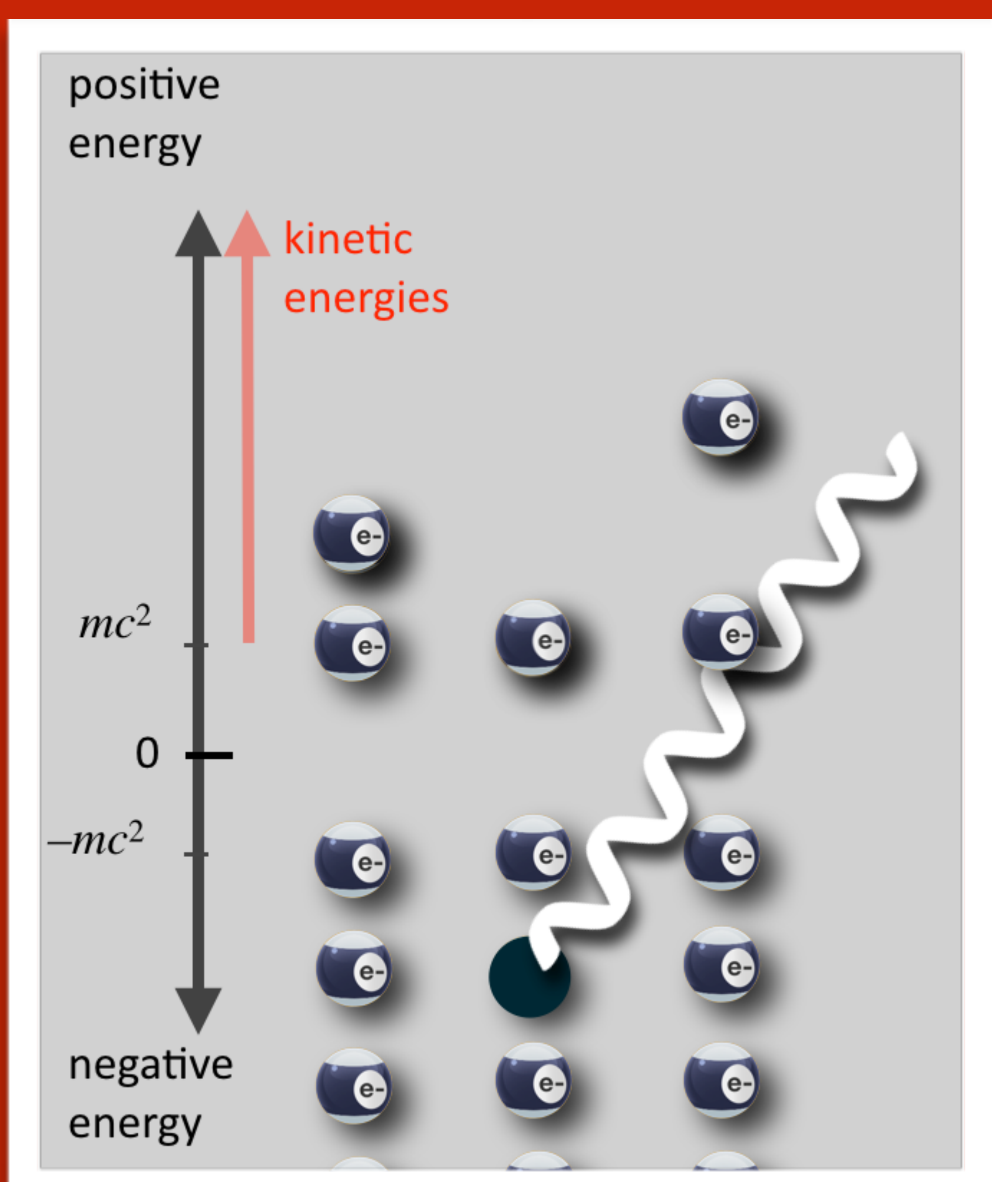
His vacuum is full of negative energy electrons





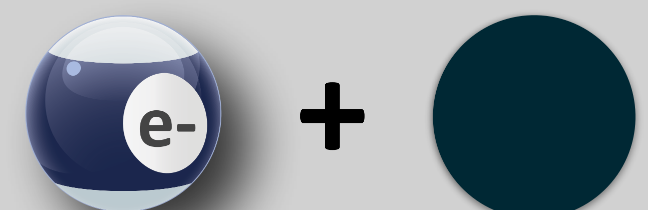
start with nothing

$$E_\gamma > 2\, m_e\, c^2$$



NOTHING

+ Energy



Let's talk about Nothing.

Dirac began this discussion

which continues today

in particle physics

and in cosmology

what is this?

$\psi(-E)$ **a positively charged object with negative energy?**

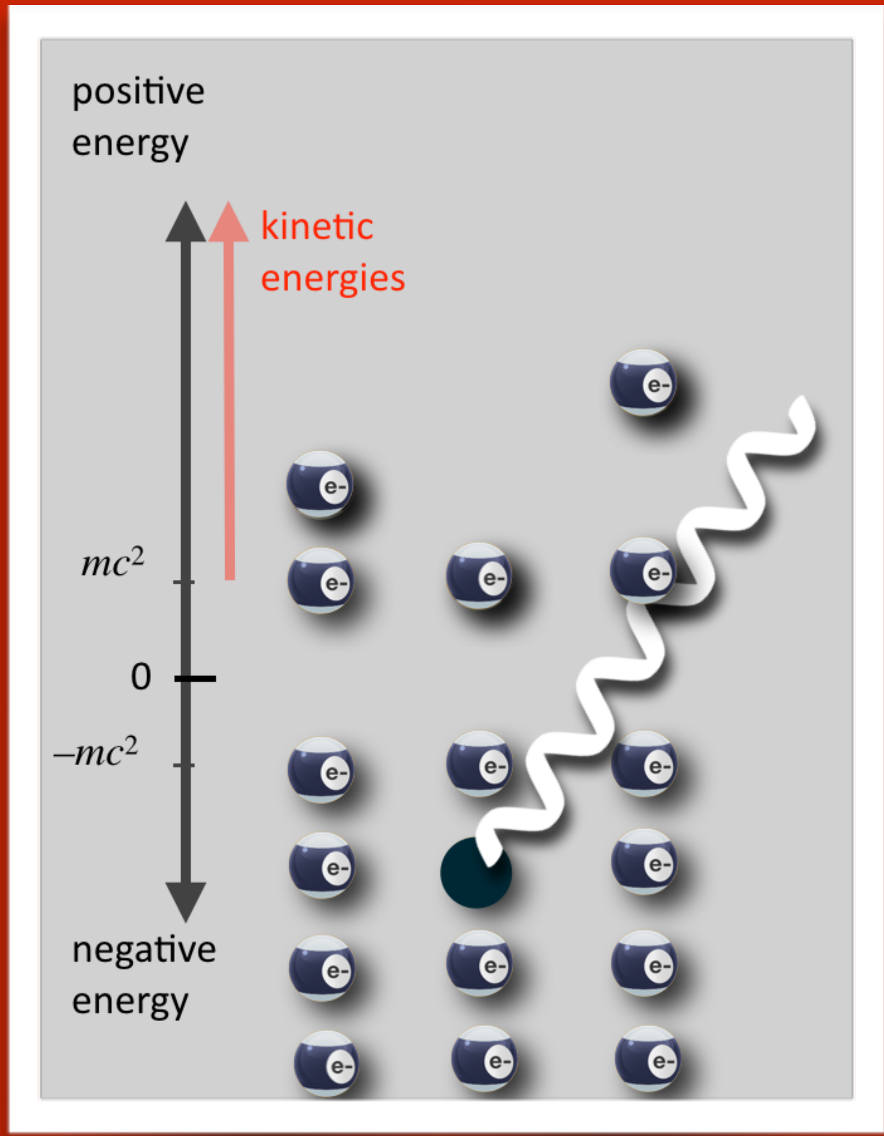
At first, he thought: “proton”

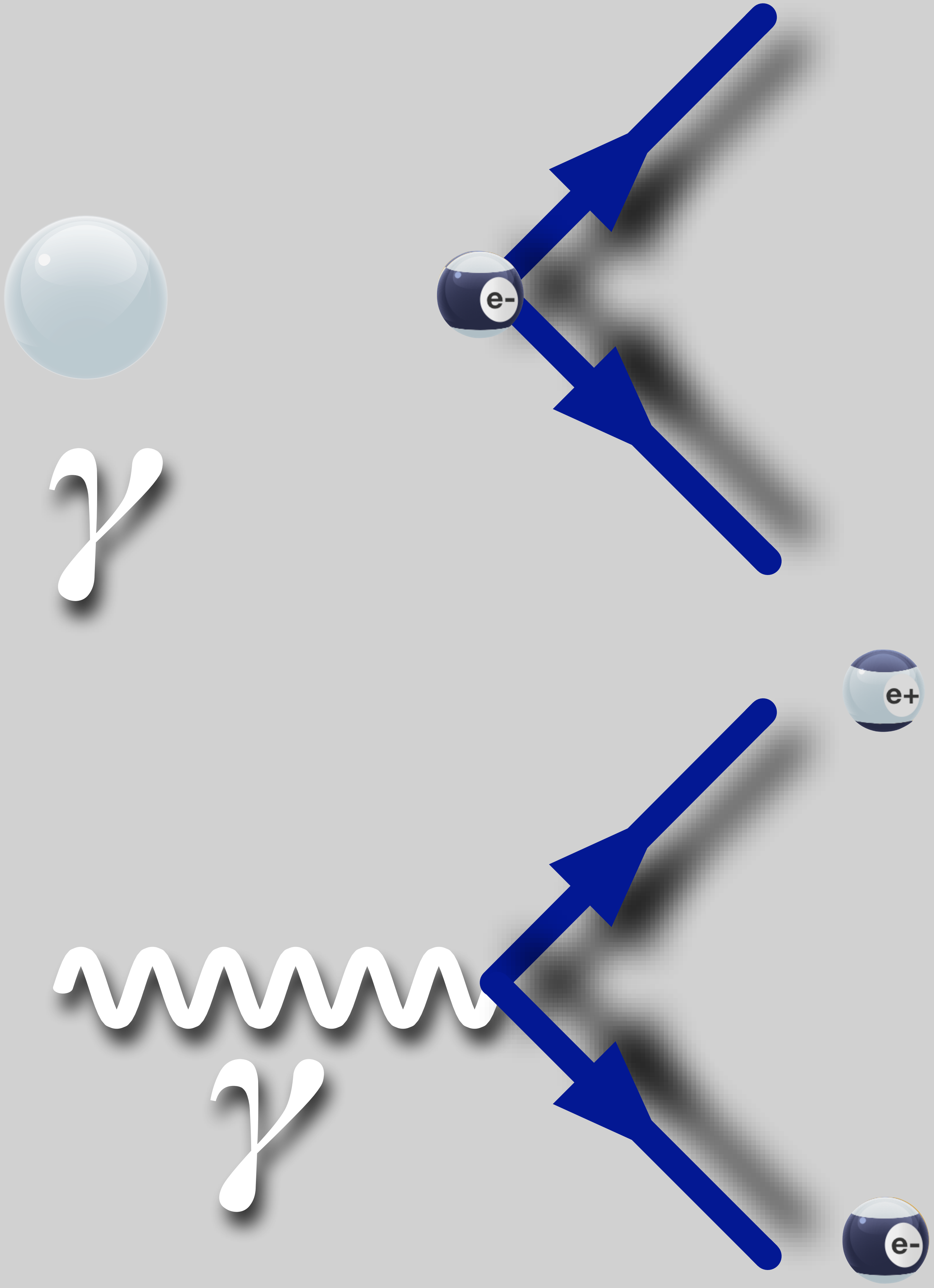
nah. A bolder idea: an anti-electron. The Positron.


Yes...antimatter.
ANGELS&DEMONS
WWW.ENTERTAINMENTWALLPAPER.COM

modern intepretat

a photon poof-disappears





The antimatter story has a happy ending:

1932

Cosmic Rays

very high energy protons from space

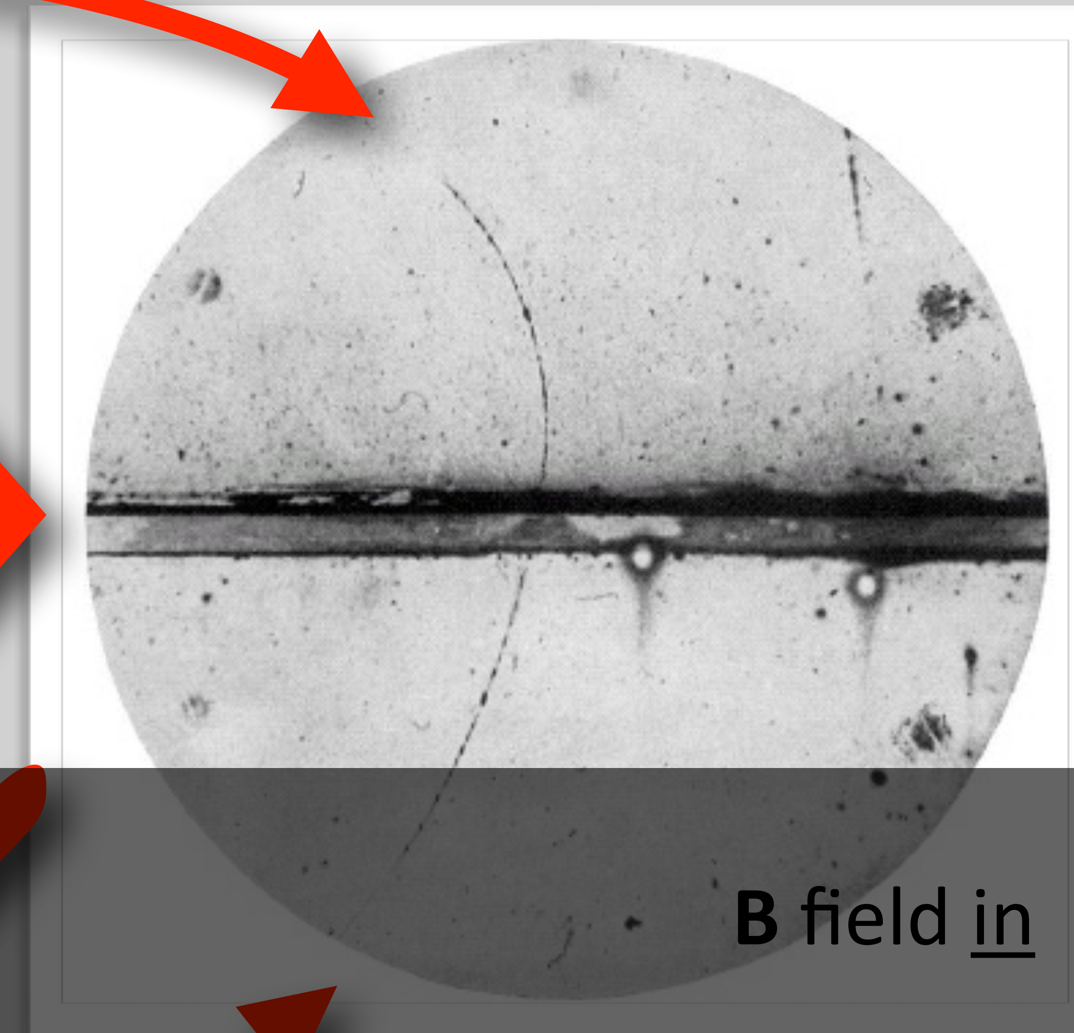
~2 per minute per fingernail

Carl Anderson

look at this track...

sharper curvature at top

clever...put in a lead plate to cause particles to lose energy

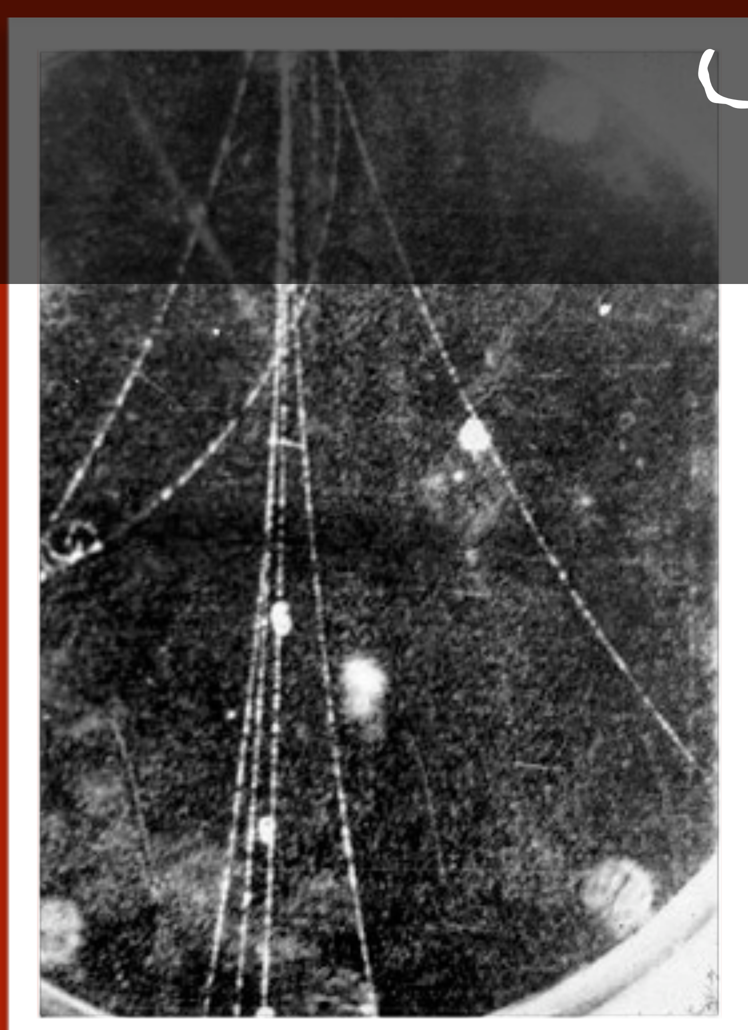


DOWN and negative?

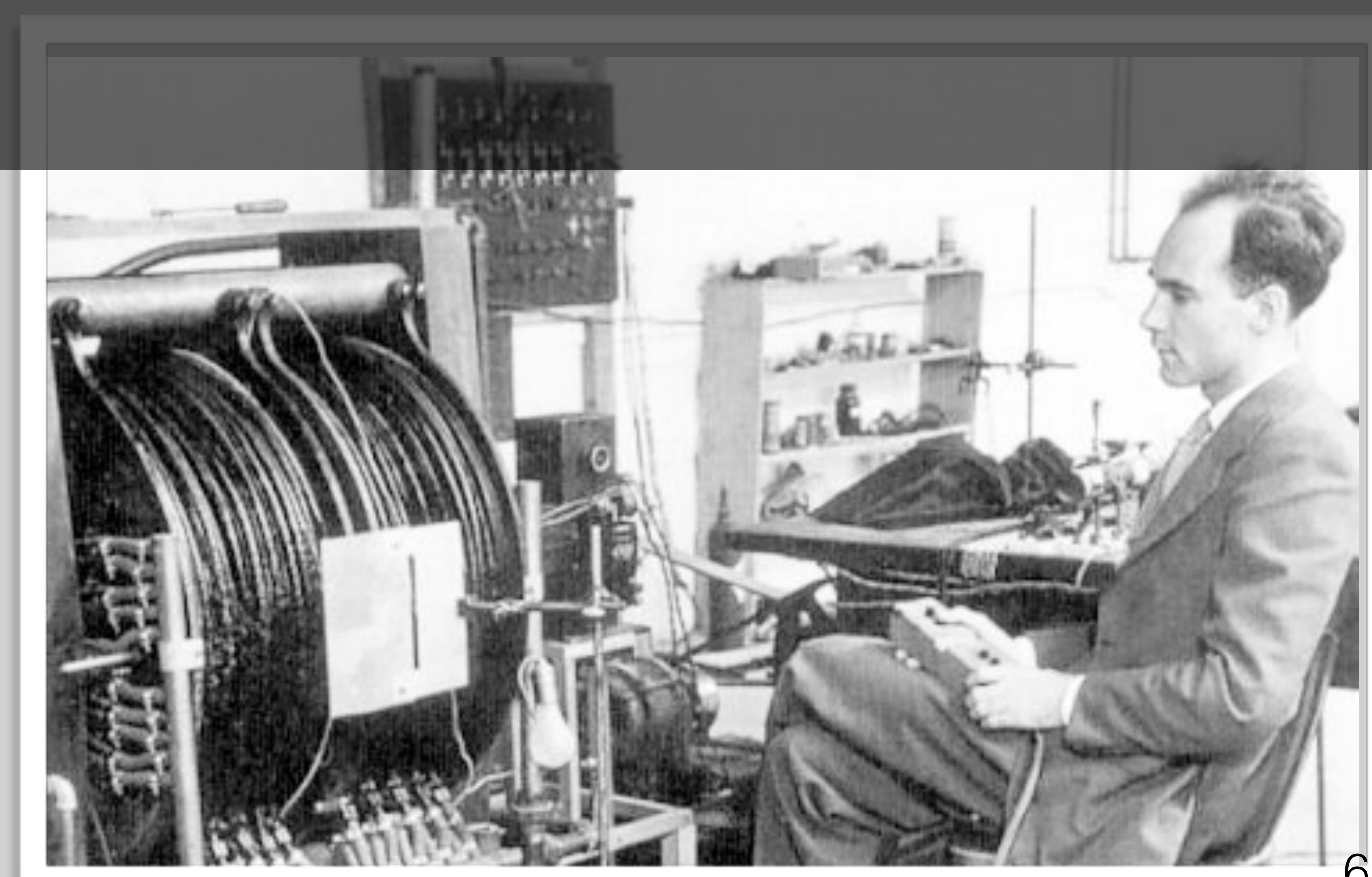
UP and positive?

Yes...antimatter.

Right on schedule: 1932



B field in



the bar over the top will mean "antiparticle"

anti-electron, aka "positron"

symbol: $\overline{e}$ or e^+

charge: +1e

mass: $m_e = 9.0 \times 10^{-31}$ kg ~ 0.0005 p

spin: *1/2*

category: anti-fermion, anti-lepton

antimatter

is a fact of life

every particle has it’s anti-particle partner

same mass, different electrical charge

Dirac Nobel

at the age of 31

Carl Anderson and Victor Hess

Anderson was 31