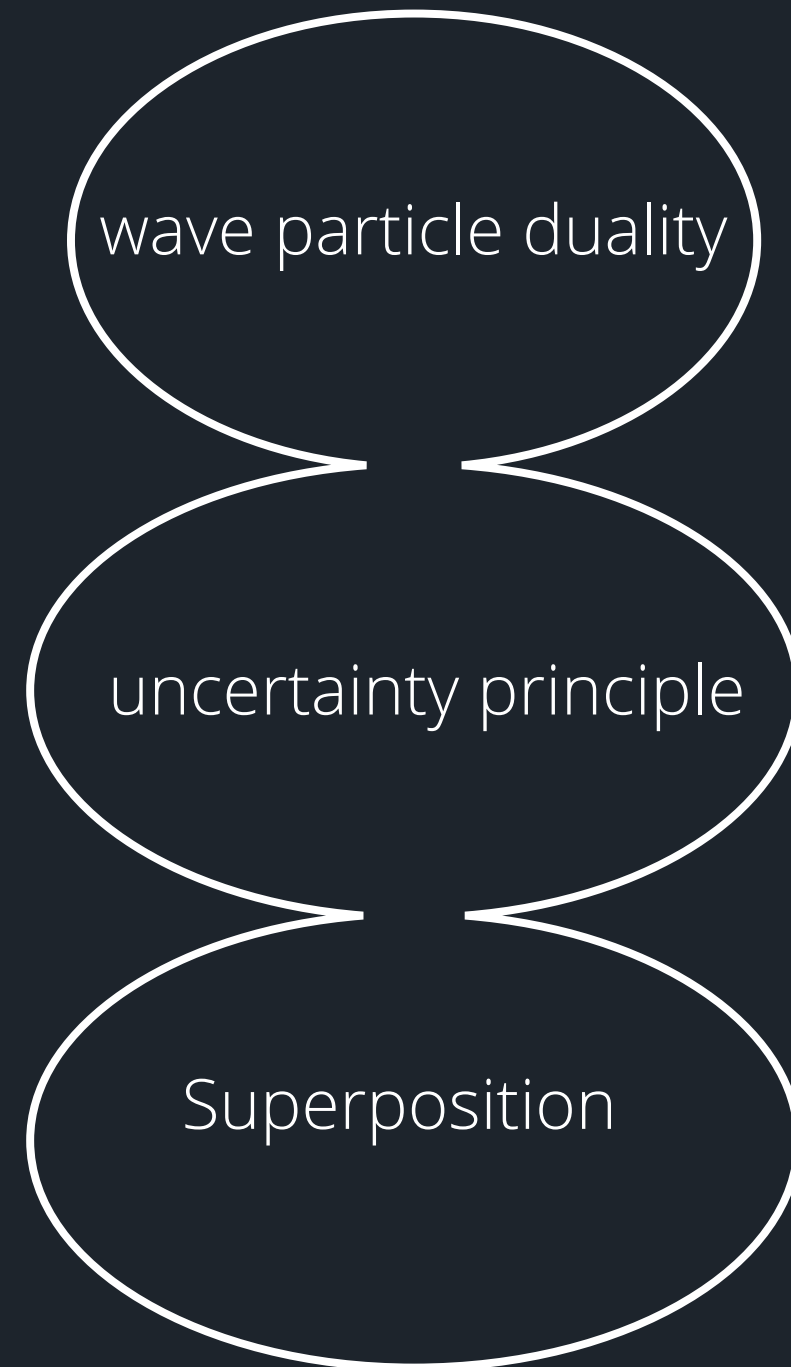


QUANTUM ENTANGLEMENT

A PEEK INTO THE QUANTUM WORLD

≡ WHY THIS TOPIC?



Today's Agenda

- What are quantum particles?
- What is the spin of a particle
- Thought experiment
- Spooky action at a distance
- Deeper reality- hidden information in particles
- John Bell's EPR experiment
- Application & Possibilities



≡ WHAT ARE QUANTUM PARTICLES

BASIC UNITS OF MATTER AND ENERGY (in simple terms)

- A Particle Is a 'Collapsed Wave Function'
- A Particle Is a 'Quantum Excitation of a Field'
- Particles 'Might Be Vibrating Strings'
- A Particle Is a 'Deformation of the Qubit Ocean']
- Particle Is an 'Irreducible Representation of a Group'

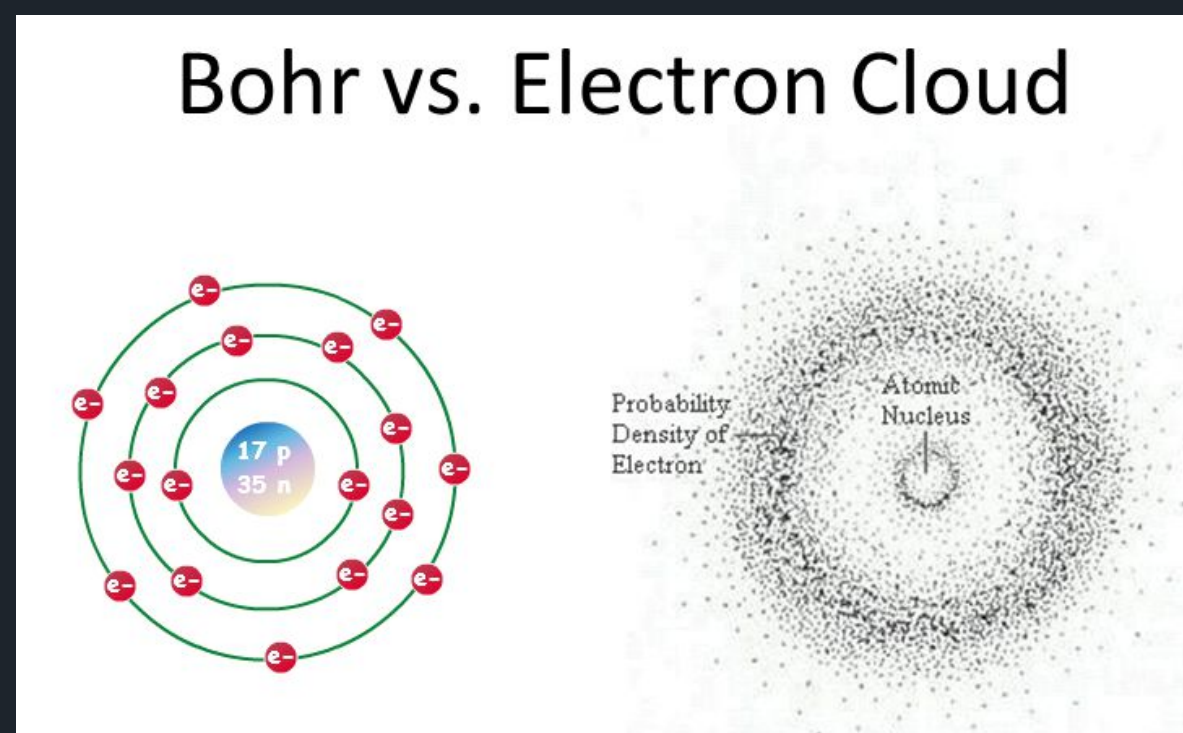
Familiar Particles: PROTONS, NEUTRONS & ELECTRONS

Other particles: up quarks, down quarks, strange quarks, charm quarks, top quarks, bottom quarks, electron neutrinos, muons, muon neutrinos, tau, and tau neutrinos, bosons, photons and gluons.



THE QUANTUM STATE

In quantum physics, a quantum state is a mathematical entity that provides a probability distribution for the outcomes of each possible measurement on a system. Knowledge of the quantum state together with the rules for the system's evolution in time exhausts all that can be predicted about the system's behavior

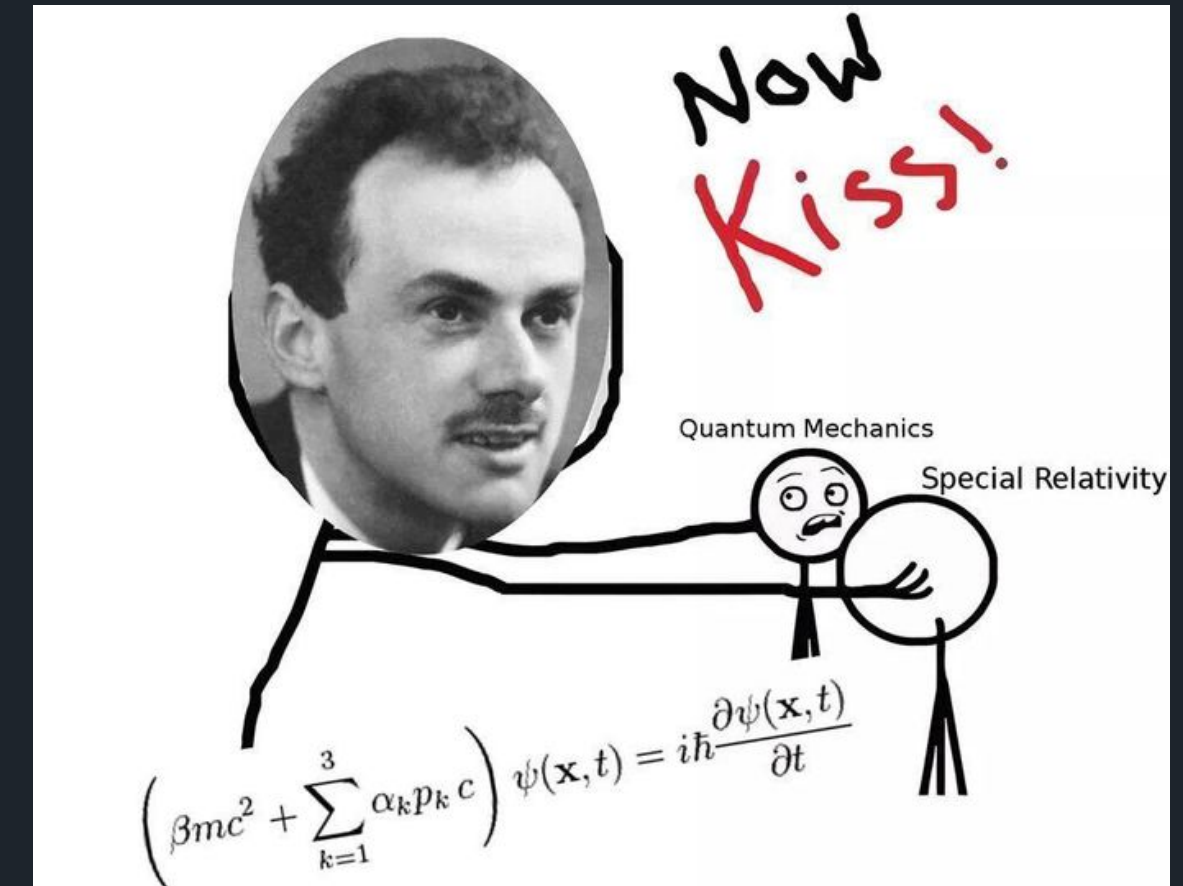




SPIN OF A PARTICLE

(not really "spin" per say)

"spin" is an inherent angular momentum of a quantum particle, and orientation in space.



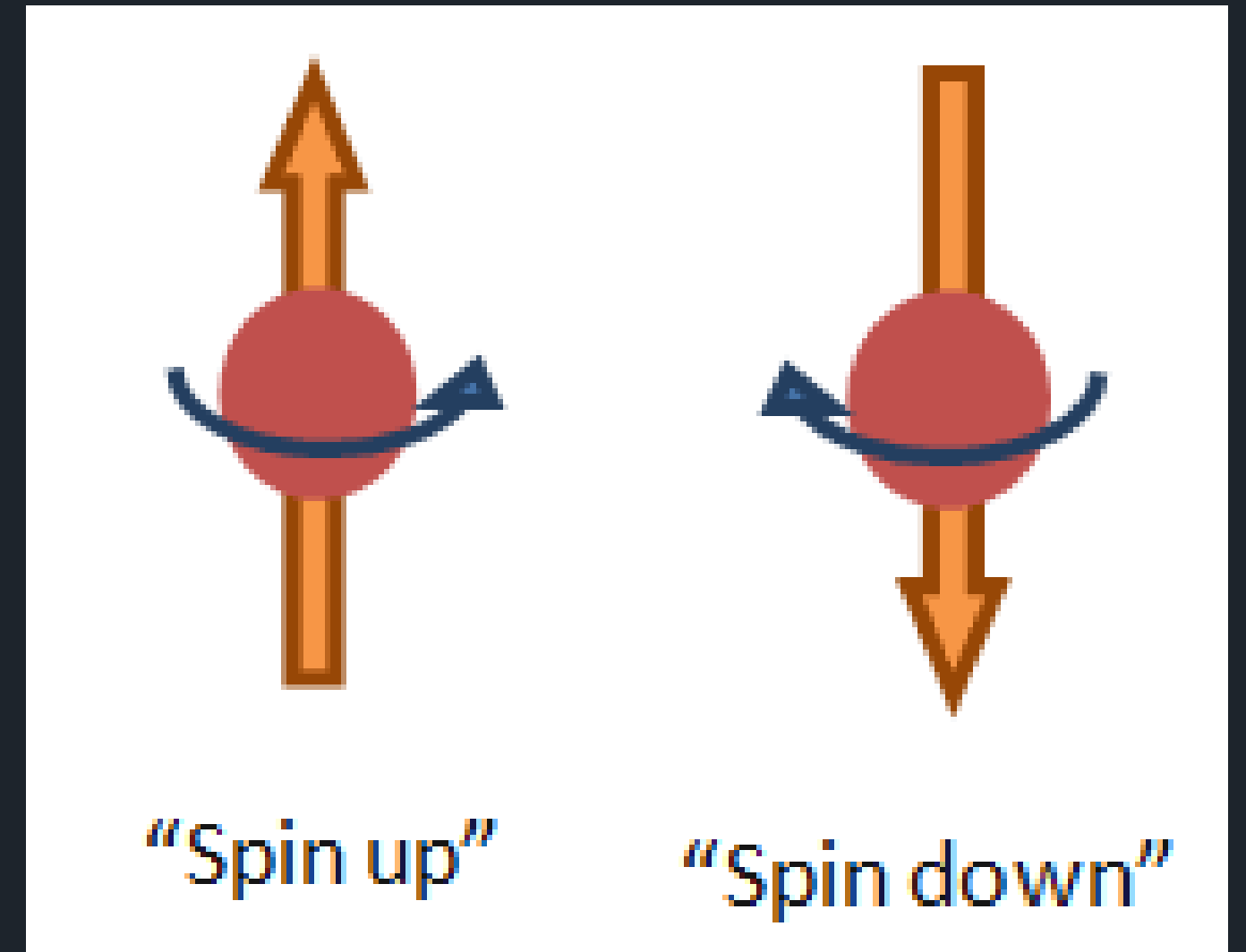
$$(\mathbf{i}\hbar\gamma^\mu\nabla_\mu - mc)\psi = 0$$

Dirac equation



HOW DO YOU MEASURE SPIN?

Initially, the spin of the particle is undefined, after measuring a particle it maintains that spin. Measuring a particle determines its spin.





LIGHT YEARS





LIGHT YEARS



QUESTIONS FOR FURTHER RESEARCH

- Are there any other spin types? What determines what spin a particle will have?
- What spin does a photon have ?
- Why is it that charged particles moving causes magnetic fields- according to Einstein?
- Do you think that eventually all quantities in physics can be explained in terms of deeper physics? Are there any examples of quantities that later on did get explained through a more encompassing theory?



SPOOKY ACTION AT A DISTANCE

If one particle is spin up then the other particle has to be spin down (if measured in the same direction), regardless of how far apart they are.

005

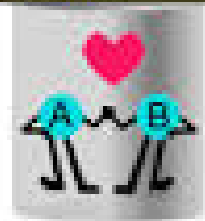
THOUGHT EXPERIMENT

It's as if the first measurement somehow influenced the result of the other...
FASTER THAN THE SPEED OF LIGHT!!

But this goes against Einstein's theory of relativity; so he proposed-
that the particles contained some hidden information about which spin they would have if measured in any direction.

SPOOKY ACTION AT A DISTANCE

A SOURCE OF PHOTONS SENDS OUT A PAIR OF ENTANGLED PHOTONS...



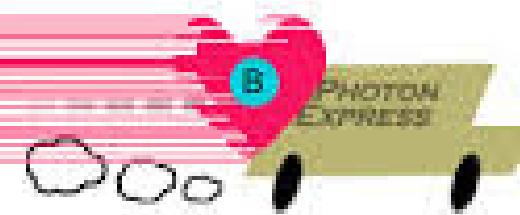
...ONE TO ALICE...

To Alice's

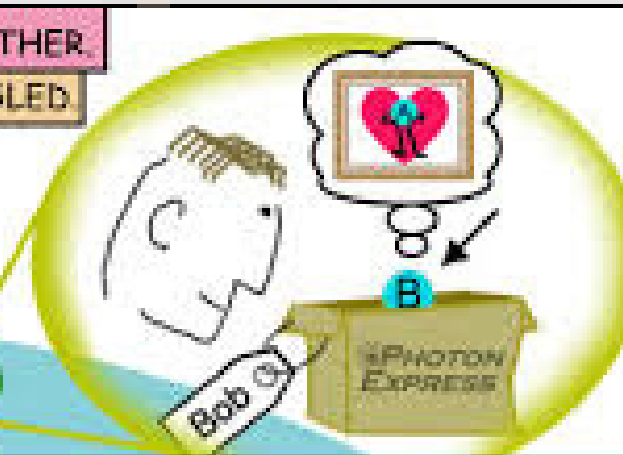


...AND ONE TO BOB.

To Bob's



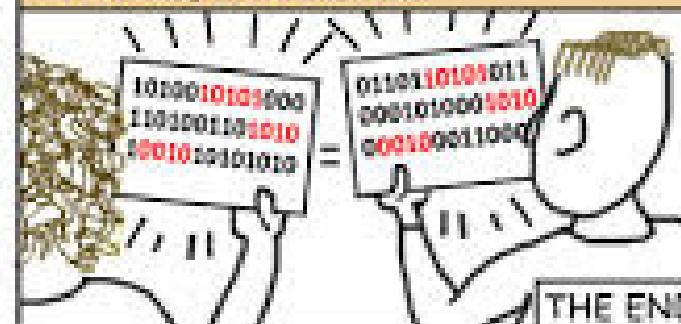
ALICE AND BOB ARE **QUITE DISTANT** FROM EACH OTHER, SO ARE THE PHOTONS, BUT THEY REMAIN ENTANGLED.



ALICE RANDOMLY CHOOSES HOW TO MEASURE THE POLARIZATION OF HER PHOTON (AND DOESN'T TELL BOB).

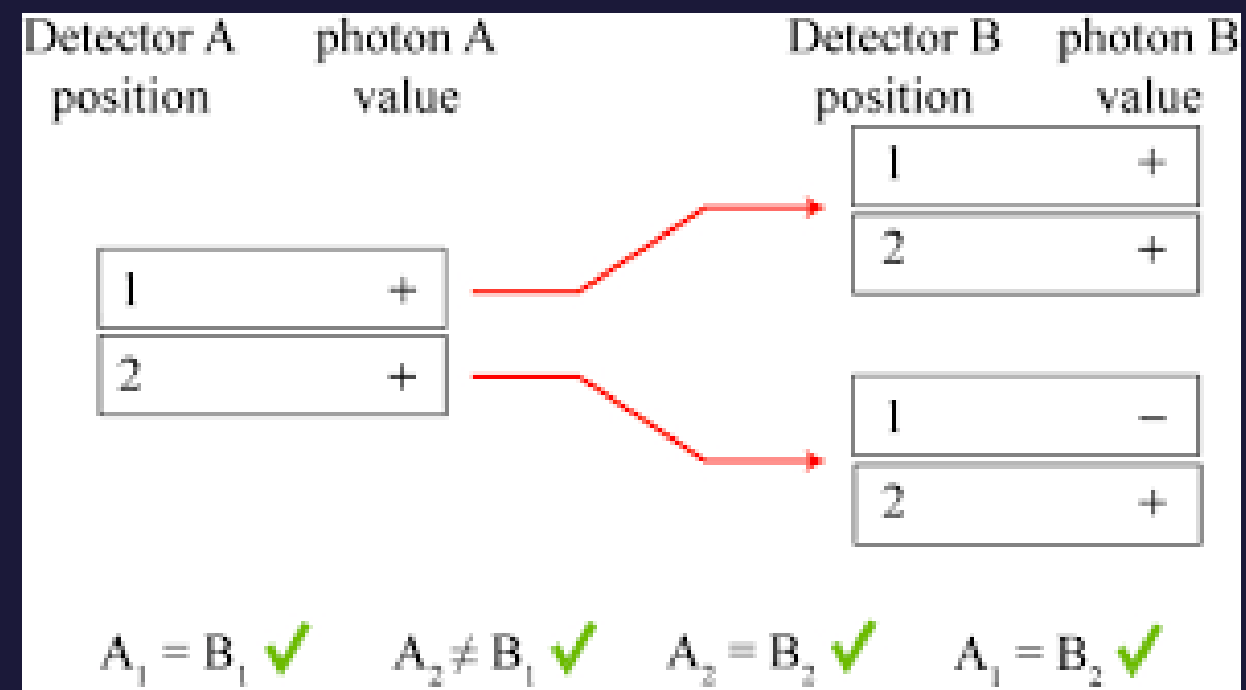
BOB ALSO RANDOMLY CHOOSES A WAY TO MEASURE THE POLARIZATION OF HIS PHOTON (AND DOESN'T TELL ALICE).

ALICE AND BOB REALIZE THAT THE **RESULTS** OF THEIR MEASUREMENTS ARE **CORRELATED**, BECAUSE THE PHOTONS--EVEN FAR APART-- ARE STILL INTIMATELY LINKED -- THAT IS, **ENTANGLED**.



JOHN BELL'S EXPERIMENT

Bell inequality test or Bell experiment, is a real-world physics experiment designed to test the theory of quantum mechanics in relation to Albert Einstein's concept of local realism.



$$P(A = B) + P(A = C) + P(B = C) \geq 1$$



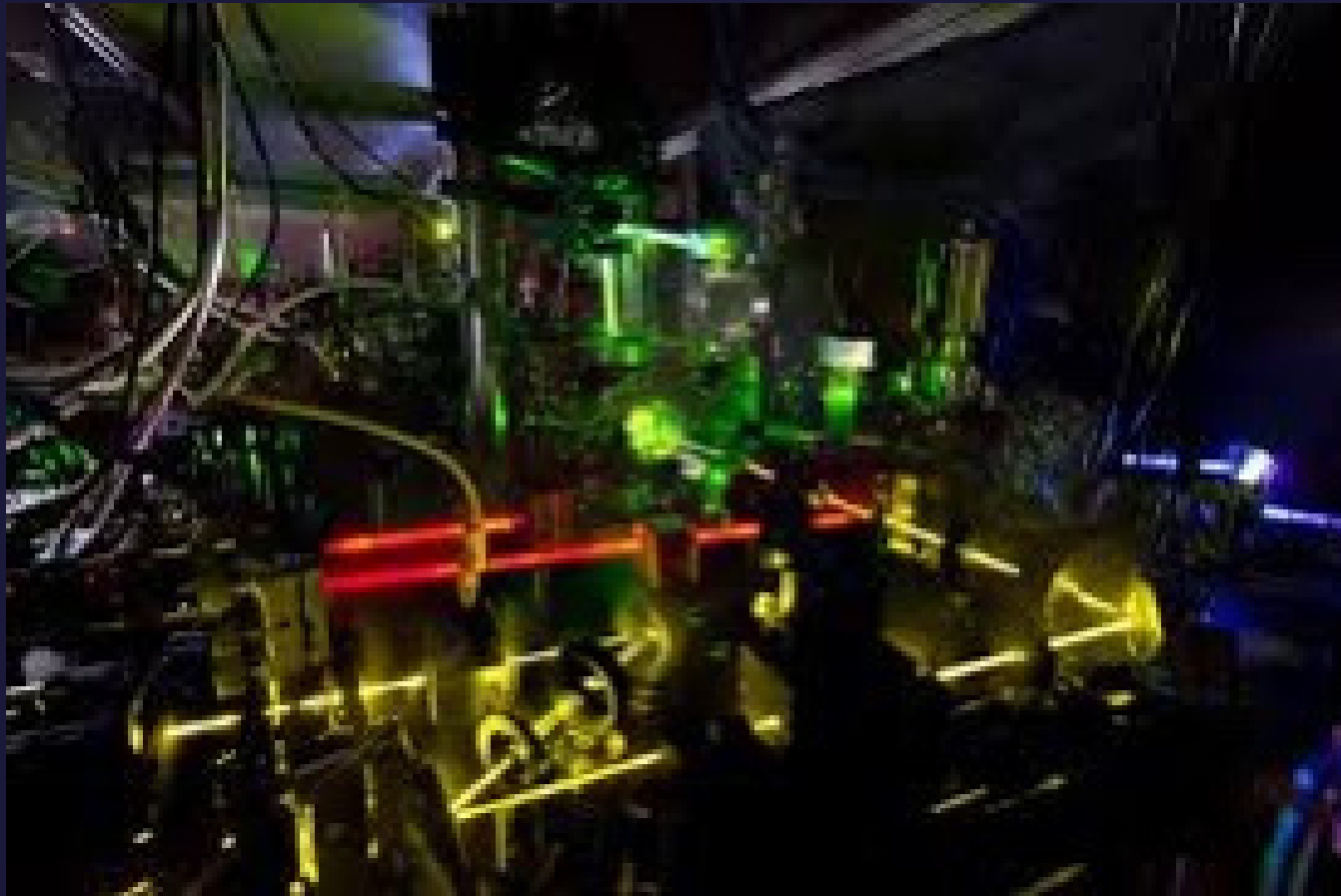
POTENTIAL APPLICATIONS

- Does this mean we can use entangled particles to communicate faster than the speed of light?!
- Atomic clocks. EG:- The quantum logic clock.

Entangled atomic systems would not be preoccupied with local differences and would instead solely measure the passage of time. Entangled clocks could even be linked to form a worldwide network that would measure time independent of location, vastly expanding the technology of GPS systems and telecommunication.

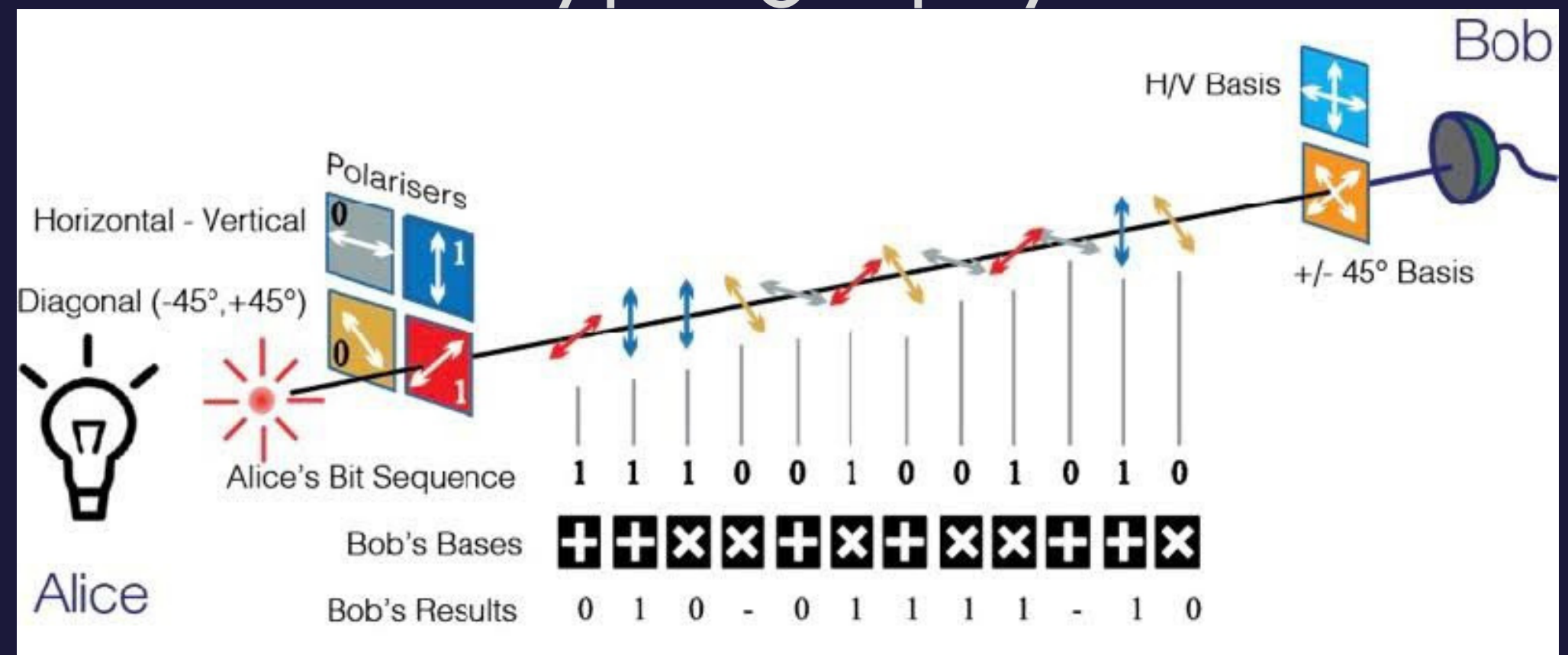
- Quantum cryptography
- Entanglement enhanced microscope
- Quantum teleportation





Quantum Logic clock

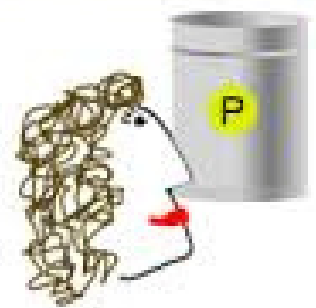
Quantum cryptography



QUANTUM TELEPORTATION

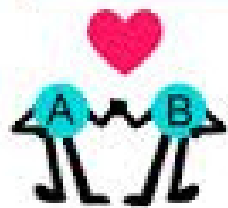
or: WHAT HAPPENS TO "A" WILL AFFECT "B"

ALICE HAS A
YELLOW PHOTON.

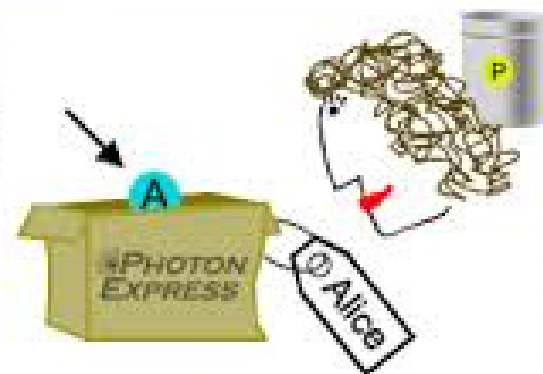


CHARLIE HAS A
PAIR OF BLUE
PHOTONS...

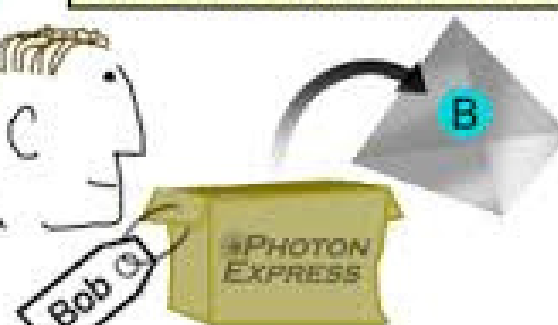
...THAT ARE
ENTANGLED!



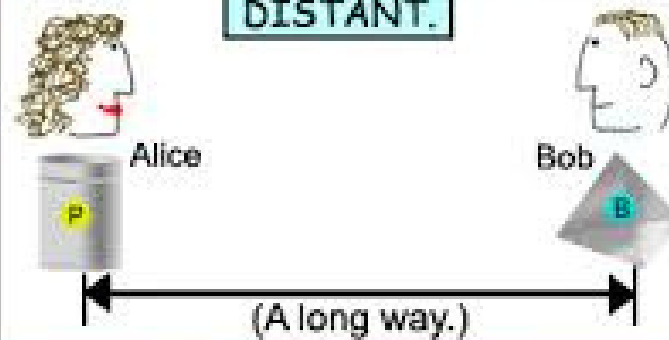
CHARLIE SENDS ONE TO ALICE...



...AND ONE TO BOB,
WHO STORES IT IN HIS
CRYSTAL "MEMORY BANK."



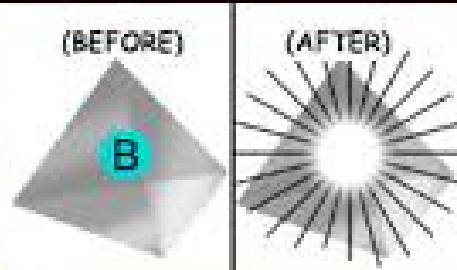
ALICE AND BOB'S RELATIONSHIP
IS CORDIAL, BUT SOMEWHAT
DISTANT.



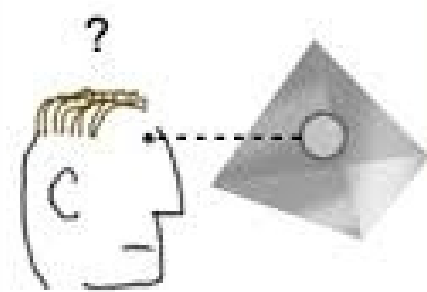
AS THE BLUE PHOTON ALICE RECEIVED
COLLIDES WITH HER YELLOW PHOTON,
SHE MEASURES THE EVENT AND LEARNS
THAT THE STATE OF HER PHOTON HAS
BEEN TELEPORTED TO BOB'S.



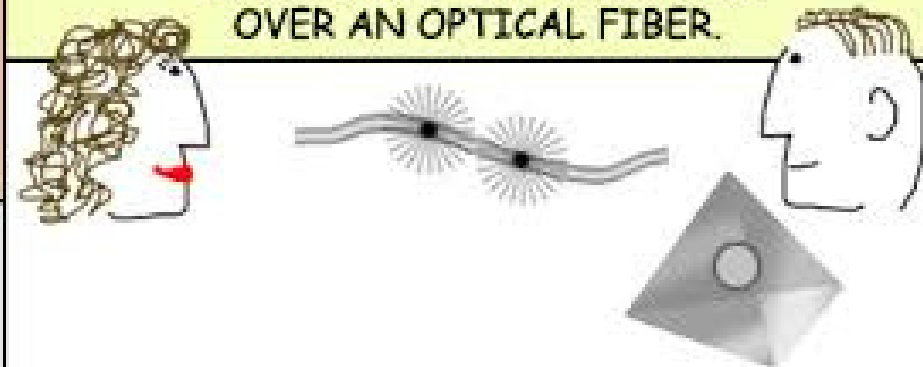
ALICE'S MEASURING OF
THE EVENT AFFECTS BOB'S
FAR-AWAY PHOTON,
CHANGING ITS STATE!



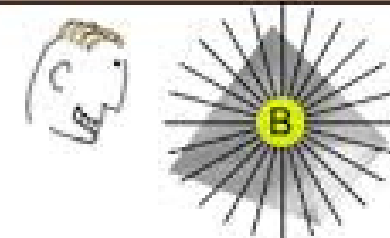
HOWEVER, BOB CAN'T DETERMINE
THAT HIS
PHOTON
HAS CHANGED.



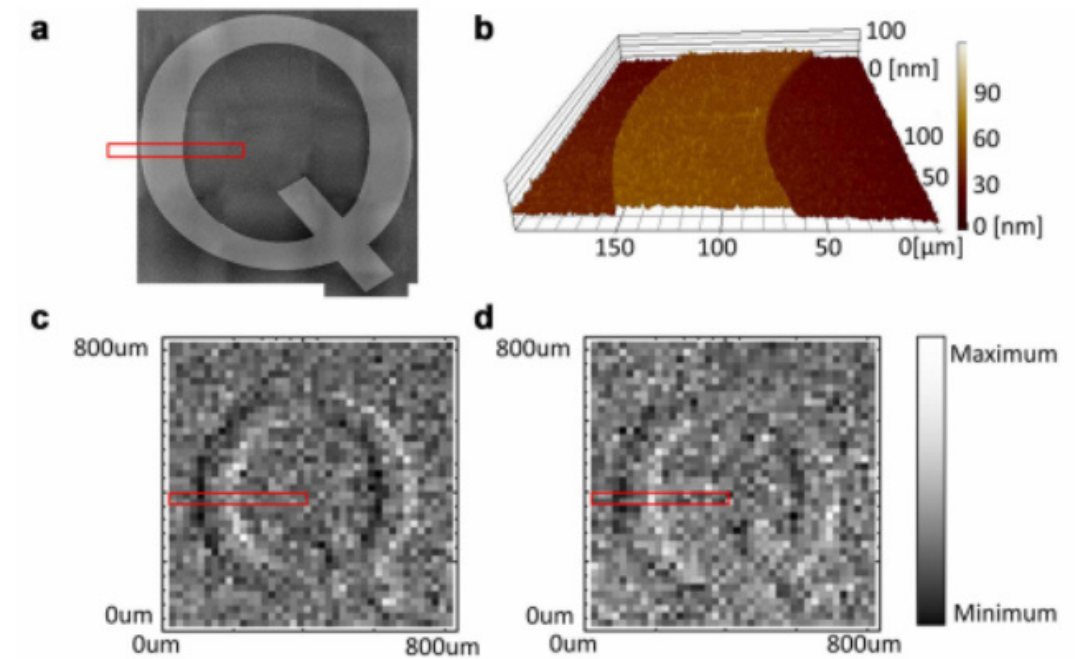
...UNTIL ALICE SENDS HIM
TWO BITS OF INFORMATION
OVER AN OPTICAL FIBER.



AND BOB LEARNS
HIS PHOTON HAS
CHANGED FROM
BLUE TO YELLOW, TOO!



THE END



entangled enhanced
microscope

≡ A SHORT CLIP FROM A VIDEO

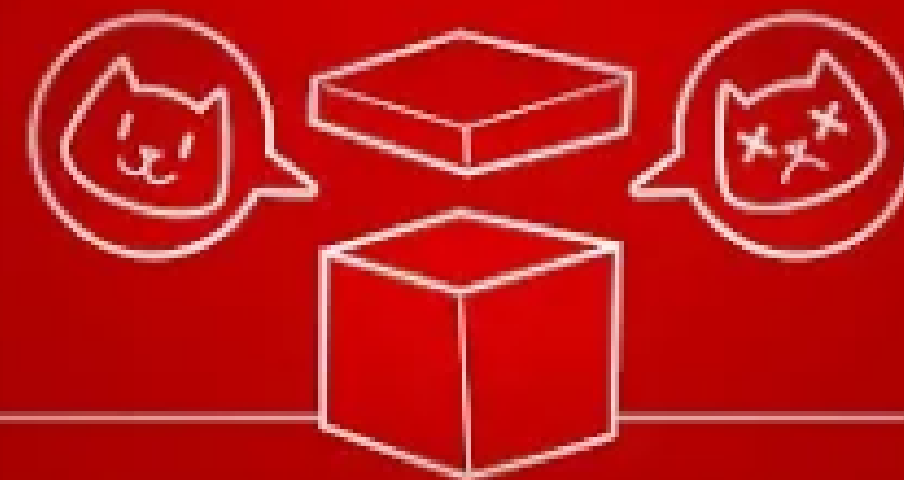
<https://youtu.be/z1GCnycbMeAths>



What can Schrödinger's cat teach us about quantum m...



WHAT IS QUANTUM ENTANGLEMENT?



Watch on  YouTube

≡ SOURCES:



1. <https://www.livescience.com/what-is-quantum-entanglement.html>
2. <https://www.youtube.com/watch?v=DbbWx2COU0E&list=WL&index=3>
3. <https://www.youtube.com/watch?v=ntxC5KMC4y0&list=WL&index=4>
4. <https://www.youtube.com/watch?v=fkAAbXPEAtU&list=WL&index=5>
5. https://www.youtube.com/watch?v=5__0o2fJhtSc&list=WL&index=6
6. <https://www.youtube.com/watch?v=hiyKxhETXd8&list=WL&index=10>
7. <https://www.sciencedirect.com/topics/mathematics/quantum-particle>
8. <https://www.quantamagazine.org/what-is-a-particle-20201112/>
9. <https://www.sciencenewsforstudents.org/article/quantum-world-mind-bogglingly-weird>
10. <https://www.quantamagazine.org/what-is-a-particle-20201112/>

≡ RECOMMENDED SOURCES:



1. The Feynman lectures, Volume 3
2. The Story of Spin.
3. A Veritasium and Minute Physics videos
4. Sneaking a Look at God's Cards - Ghirardi.
5. Quantum Physics of Atoms, Molecules, Solids, Nuclei, and Particle Physics- Eisberg and Resnick



THANK YOU

Feel free to make this an open discussion for questions



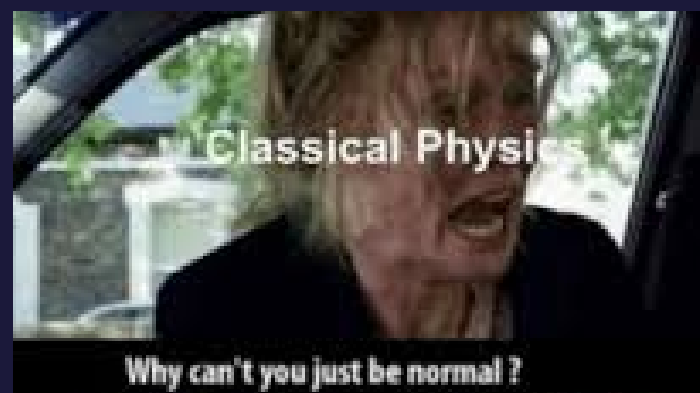
The first time you read about quantum mechanics:



The 1000th time you read about quantum mechanics:



Trying to work out the direction of the magnetic field caused by a current like



Physics at quantum level:



What does a subatomic duck say?

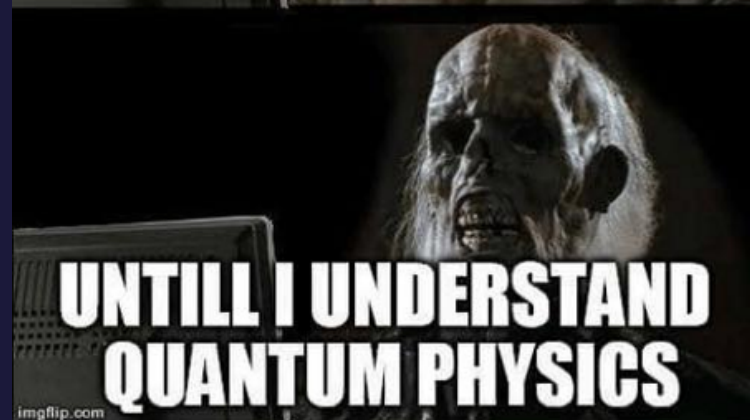


QUARK!

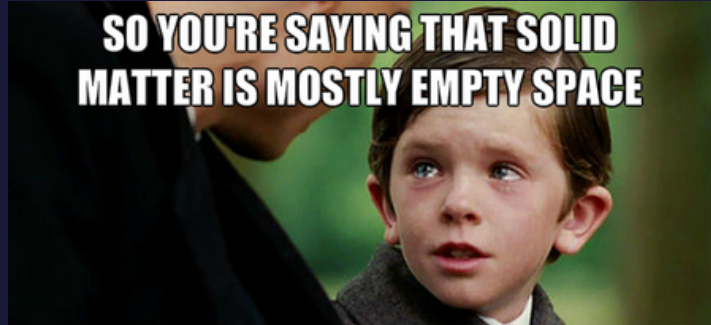
I'LL JUST WAIT HERE



UNTILL I UNDERSTAND QUANTUM PHYSICS



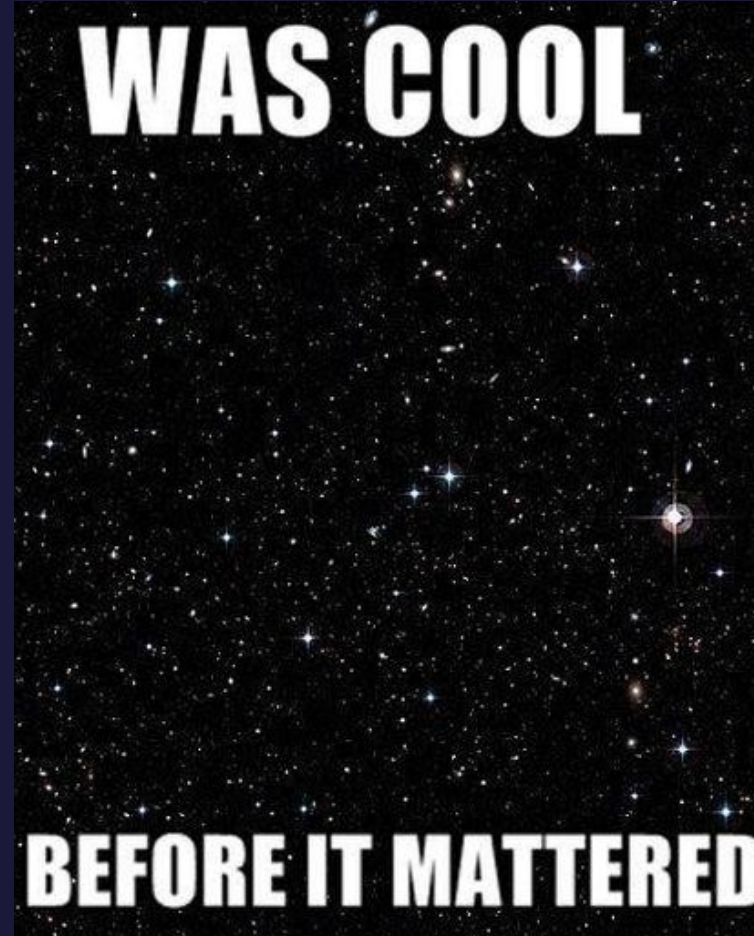
SO YOU'RE SAYING THAT SOLID MATTER IS MOSTLY EMPTY SPACE



AND EMPTY SPACE IS FULL OF VIRTUAL PARTICLES POPPING IN AND OUT OF EXISTENCE



WAS COOL



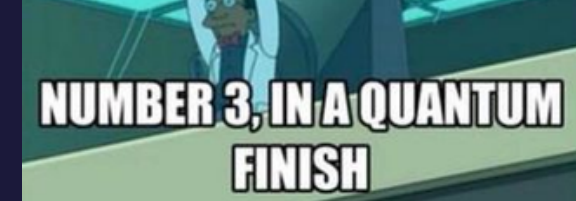
BEFORE IT MATTERED



IT'S A DEAD HEAT



AND THE WINNER IS



NUMBER 3, IN A QUANTUM FINISH



THEY'RE CHECKING THE ELECTRON MICROSCOPE



NO FAIR!



YOU CHANGED THE OUTCOME BY MEASURING IT!!

logic: *exists*

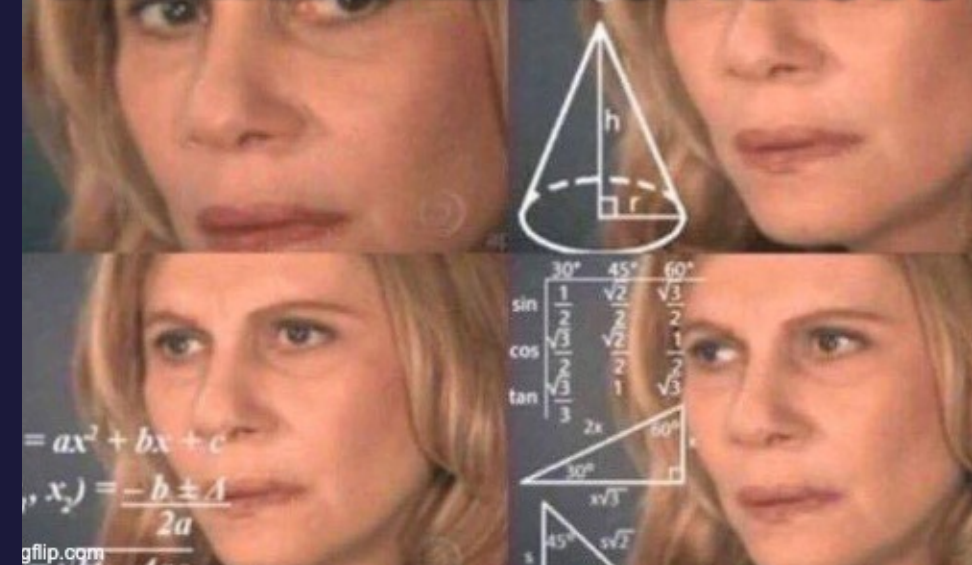
quantum physics:



What's the time, Einstein?



MEANWHILE PHYSICISTS



A NUMBER

THERE'S SOMETHING I HAVEN'T
SEEN IN A LONG TIME

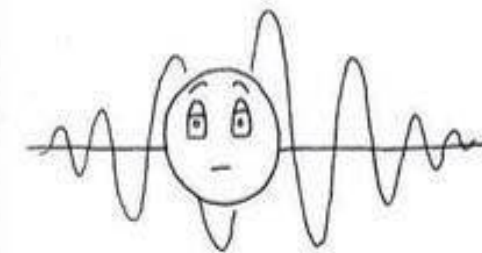
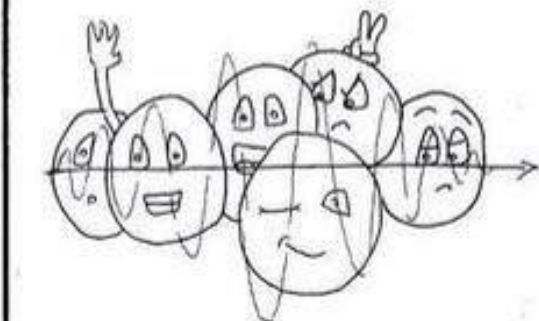
lip.com

MOMENTUM



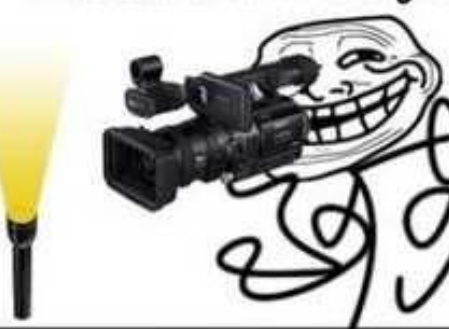
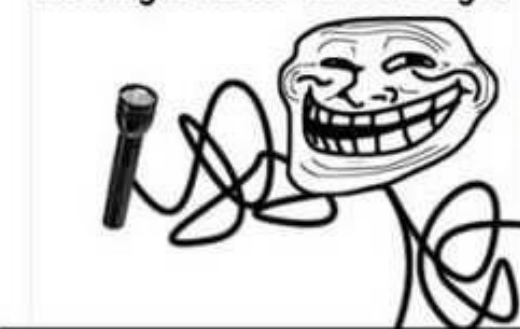
QUICK! HERE COMES THE PHYSICIST!

... ACT COOL...



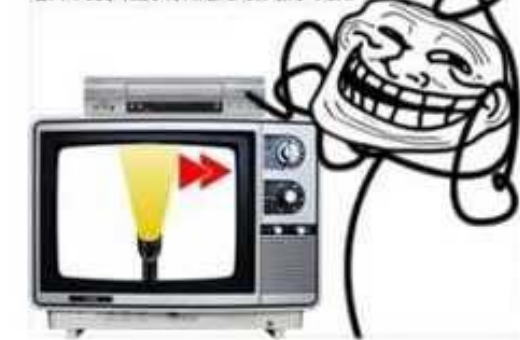
"Nothing is faster than the light"

1. Record video of the light



2. Press fast forward on the VCR.

PROBLEM,



You have now created something
faster than the speed of light !

EINSTEIN ?

A PHOTON CHECKS INTO A HOTEL AND
IS ASKED IF HE NEEDS ANY HELP WITH
HIS LUGGAGE.



"NO, I'M TRAVELLING LIGHT."

