Osher Lifelong Learning Institute at UNT

The Observer and the Observed: A Dialogue Between Quantum Physics and Indian Thought

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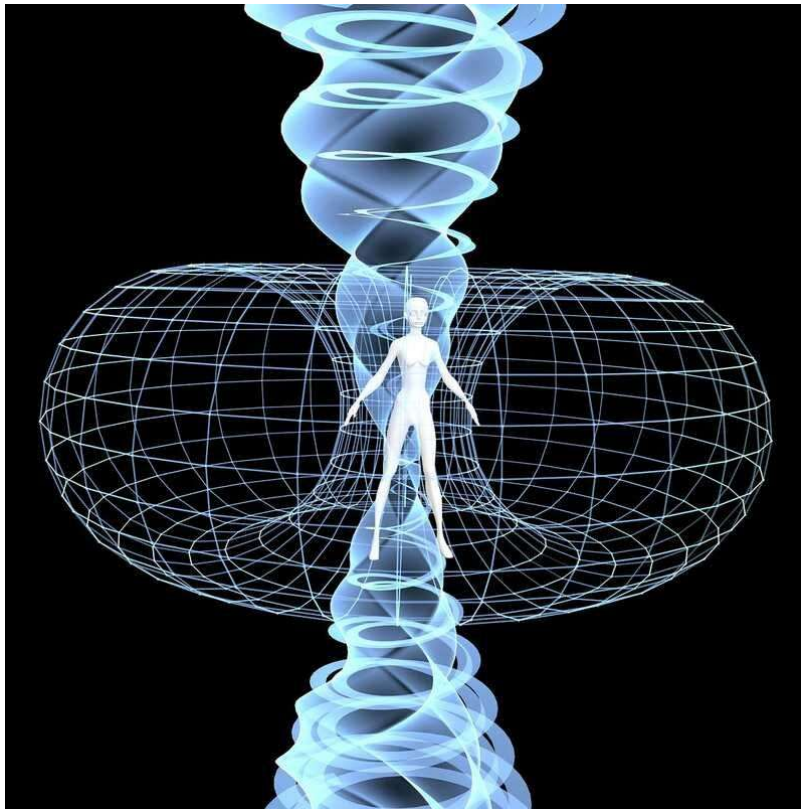
. "A mind stretched to a new idea never returns to its original dimensions." Oliver Wendell Holmes



By Richa Yadav *Ph.D.*

Class Structure

Part 1 Quantum Ideas

"Solid World" (Classical Physics)

"Breaking Point" (The Early Experiments)

Concepts explaining “Quantum Weirdness” (Modern development)

Part 2 Indian Philosophy

Physics and Philosophy

- Probe a fundamental question i.e. What is basic substance and what is the nature of reality?

- The Cartesian Dualism- 1) The observer (Mind) and the observed (Matter) never touch 2) The world could be described objectively, i.e. without ever mentioning the human observer

- Realism- Objective description of nature became the ideal of all sciences

The Foundation: A World We Think We Understand

Isaac Newton: Represents "Classical Mechanics"—the idea that the universe is a predictable machine with fixed laws of motion

The universe was a giant, predictable machine

- **Smooth and Continuous:** Space & time were like an empty stage. Objects moved in smooth, unbroken lines
- **Determinism:** Position and speed of every particle, can perfectly predict the entire future

Newtonian Mechanics

- An **intuitive** picture of the world is like a **head or tail**. Describes very basic action and reaction; describes matter as made of **particles with definite position and velocity**
- They have **fundamentally incompatible properties**: **particles** always have an exact location and move along one direction, while **waves** are vibrations which propagate in all directions
- This dual ontology remained the orthodoxy for a long
- Classical view of cause and effect
- "Billiard Ball" universe

Quantum Mechanics

What is Quantum?

Derived from the same root as the word **quantity**. It's the strange principle that on a small enough scale, the **universe seems to work in discrete quantities rather than operating on one continuous scale**. This is a little unintuitive

What is Quantum mechanics?

A branch of physics that explores the **behavior of matter and energy at the smallest scales, such as atoms and subatomic particles- electrons and photons and particles of light**

What is Quantum Physics

- Focuses on building blocks of matter to study how those particles move

- It describes a world where particles do not follow deterministic paths but instead **behave according to probabilities**

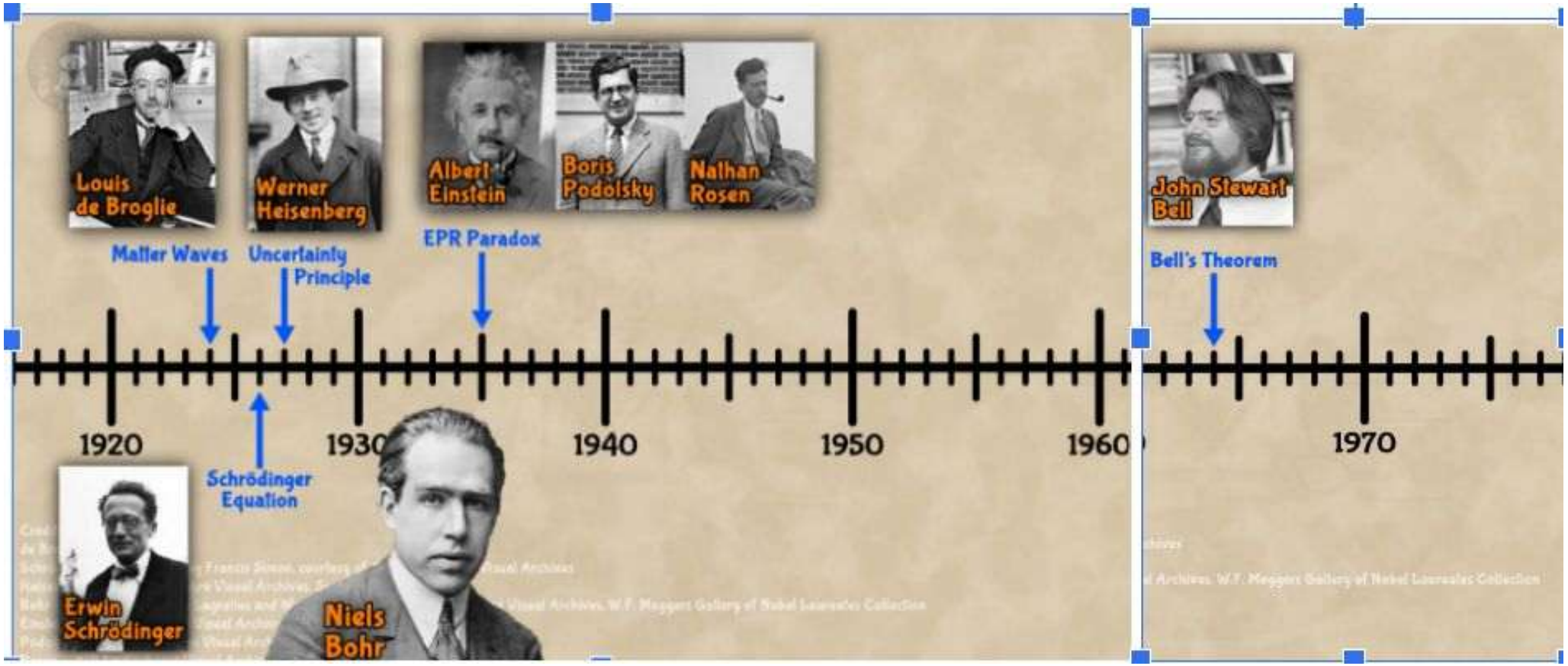
- It changed how we define reality, moving from **certainty** to **probability**

What is Quantum Physics

- **The "Single System" Idea-** Normally, we think of two particles as two separate "things," like two different marbles. But when particles are **entangled**, they stop being individuals. They become a single mathematical entity
- Space—the distance between two objects—doesn't actually matter to the particles involved
- Imagine a **single coin** that is so large its "Heads" side is in London and its "Tails" side is in New York.
- It is still **one coin** and if it’s flipped in London to see "Heads," the person in New York *instantly* knows their side is "Tails." **No signal had to travel** as they were always part of the same object

Breakthrough Experiments and the Beginning of 20th C

- Max Planck (1858-1947) revolutionized physics by proposing that energy is radiated in discrete, finite packets called "quanta" rather than continuously
- Albert Einstein (1879-1955)
- Louis de Broglie (1892-1987) proposed that sometimes matter, so far understood as particle-like, behaves like a wave
- John von Neumann (1902-1957) provided the mathematical foundation for quantum mechanics, in 1932
- Bell (1928-1990) Theorem (1964) proved that no physical theory of local hidden variables can reproduce all predictions of quantum mechanics


Louis de Broglie
Werner Heisenberg
Albert Einstein
Boris Podolsky
Nathan Rosen
John Stewart Bell
Matter Waves
Uncertainty Principle
EPR Paradox
Bell's Theorem
1920
1930
1940
1950
1960
1970
Schrödinger Equation
Erwin Schrödinger
Niels Bohr

The Developmental Phase of Quantum Physics

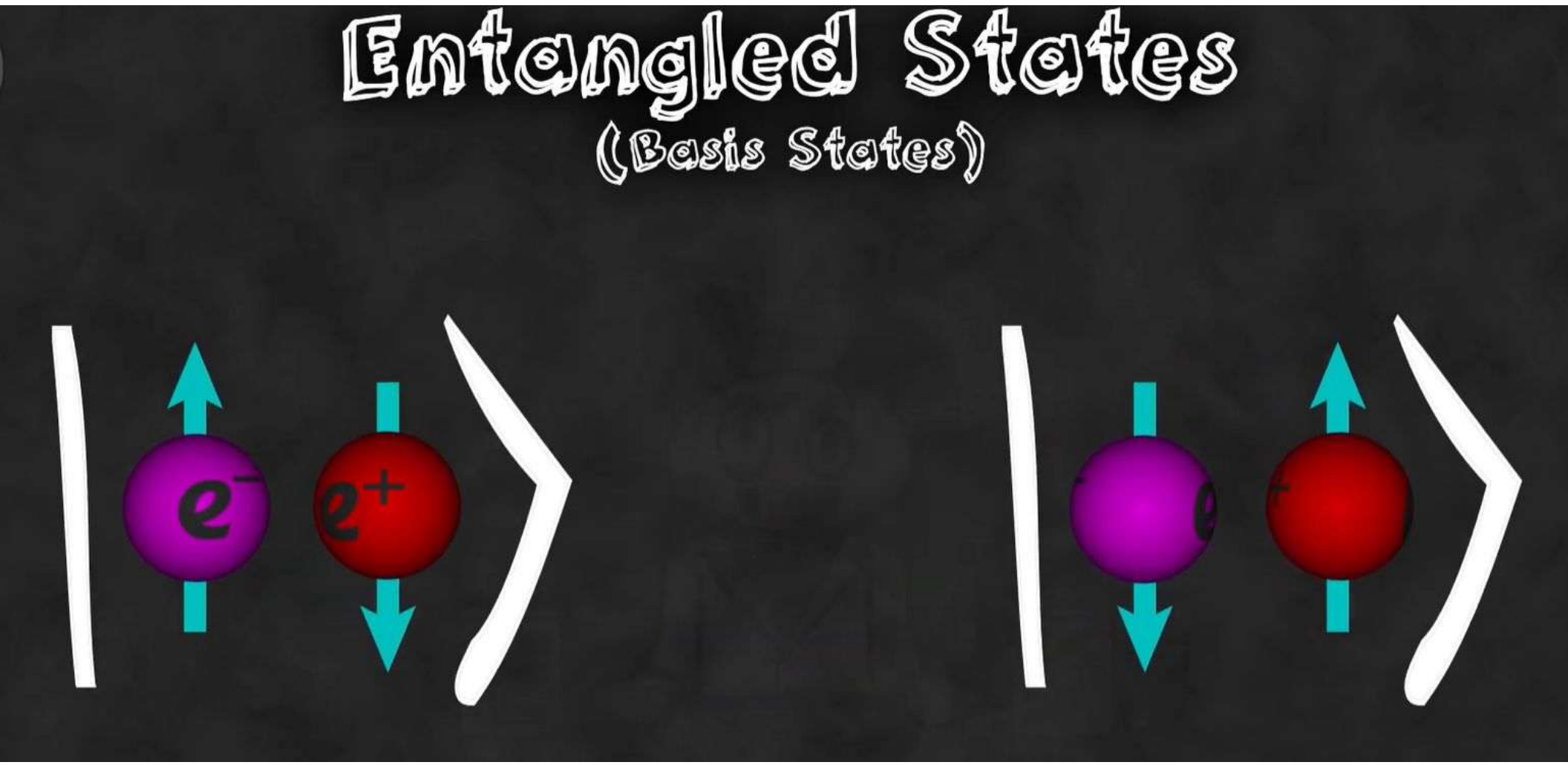
- **Einstein:** He’s the bridge- While he revolutionized physics with Relativity, he struggled with Quantum Mechanics providing the perfect "skeptic" voice

  Einstein’s transition: Newton’s "fixed stage" was an illusion

- **Special Relativity:** He proved that space and time aren't fixed—they stretch and squeeze. **Time is relative**
- **The Photon:** He showed that **light isn't just a smooth wave; it’s made of "chunks" (photons)**. This was the first major blow to the "continuous" world of Newton
- **Energy-Mass:** Through $E=mc^2$, he showed that matter and energy are two sides of the same coin

Entangled States

(Basis States)



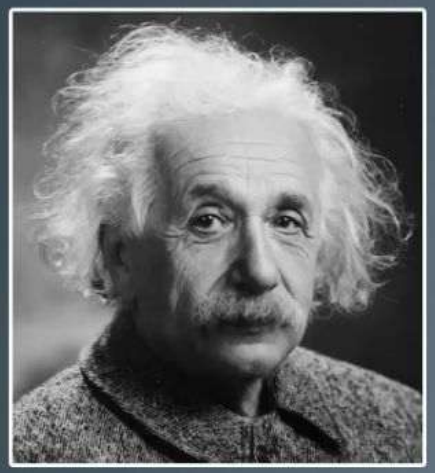
Quantum Entanglement: **Departure from Classical Line of Thought**

- Situation wherein two particles have their properties **magically linked or entangled** and certain aspects of one particle depends on the aspects of the other particle, regardless of how far apart they are
- In 1935, Einstein, Podolsky, and Rosen recognized that qm is **inherently non-local**, so an action in one place can instantly influence something on the other side of the universe, in no time at all
- **Quantum Nonlocality-**Quantum particles are **neither** Left nor Right until you look. They are both at once. The "choice" happens the moment you measure them, and that choice is **reflected across the universe instantly**

Einstein’s Theory of Relativity

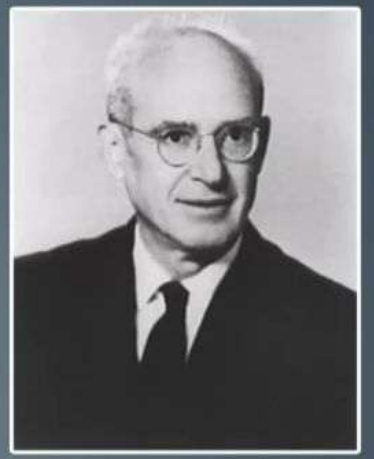
- **Local realism**: objects have definite properties even when we aren't looking at them, and information cannot travel faster than light
- His nobel prize-winning paper on the photoelectric effect explained how **light could behave as a particle** even though most scientists around the time thought that light behaved as a wave
- **Locality:** Nothing can travel faster than the speed of light. An action "here" cannot instantly affect something "there."
- The math of quantum mechanics didn't tell the whole story of reality

EPR Paper



Albert Einstein
German-born physicist
1879-1955

Boris Podolsky
Russian-American physicist
1896-1966



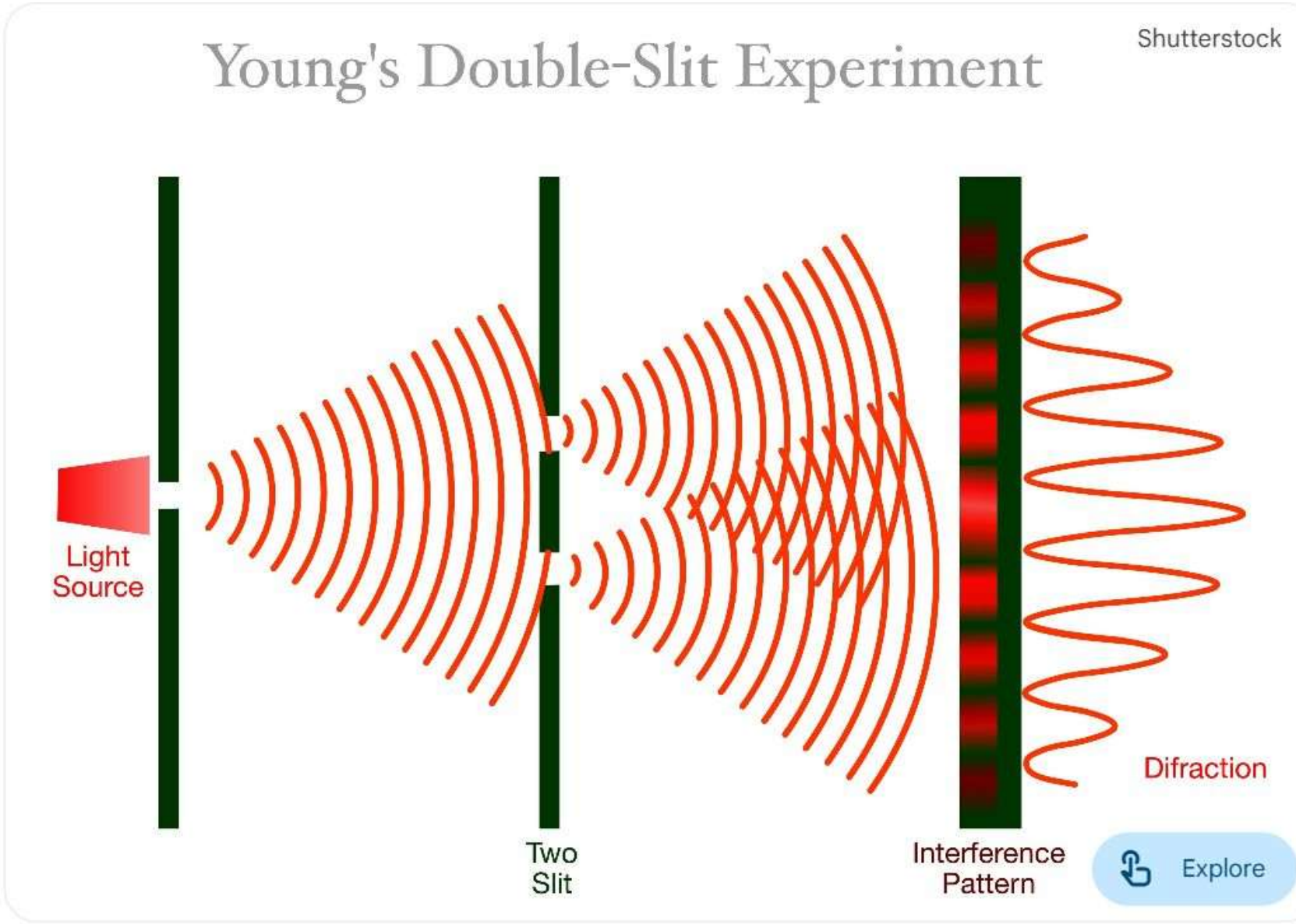
Nathan Rosen
American-Israeli physicist
1909-1995

Einstein’s Theory of Relativity

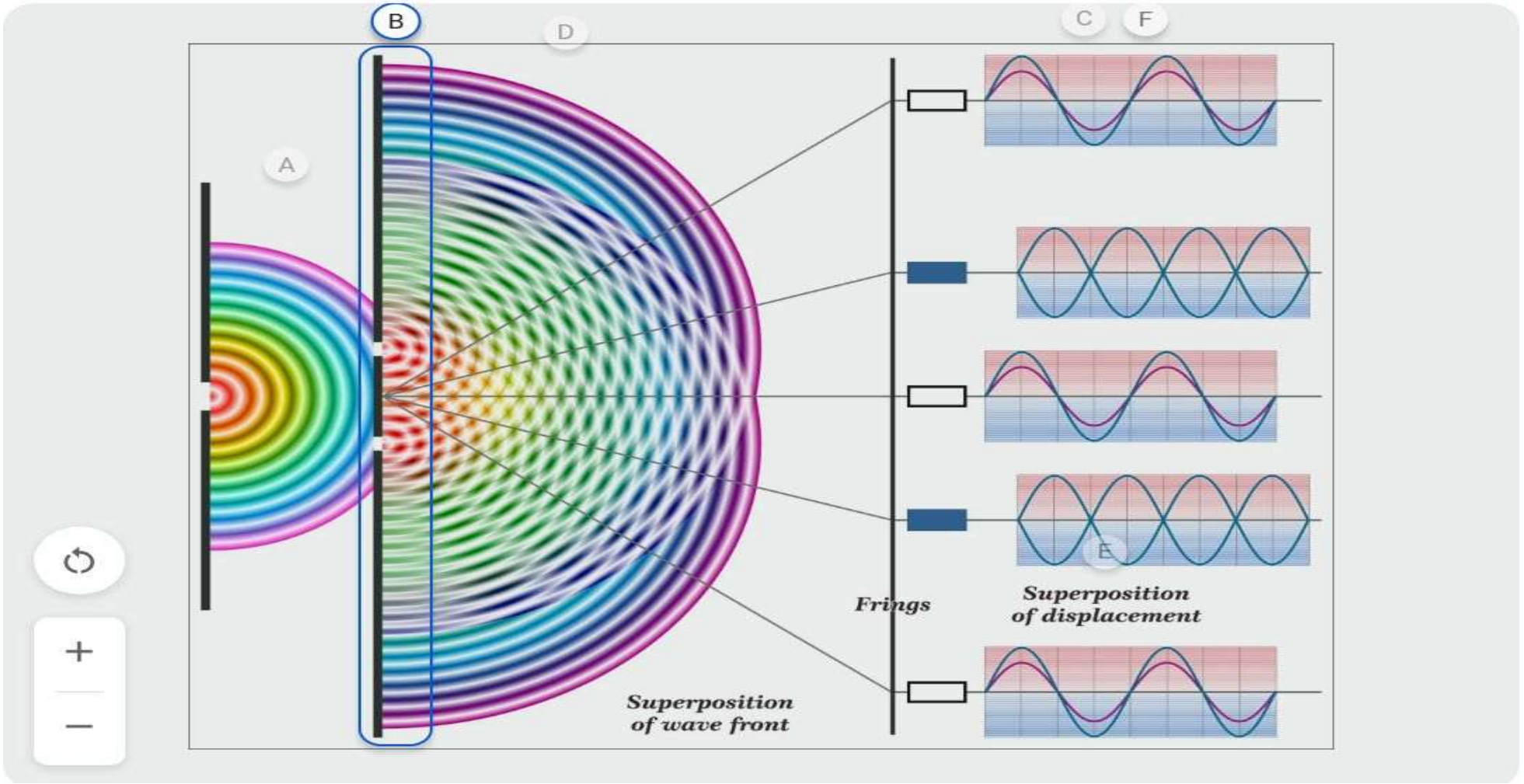
- If measurement of entangled quantum particles is made, they will essentially behave **as one big system irrespective of how far they are placed** without even having to wait for light to come from that particle and reach us simply because we'd made a **measurement on the particle near us**
- **EPR Paradox 1935-** quantum mechanics was missing something
- If two particles were linked, measuring one would "instantly" affect the other; the particles must have **"pre-programmed" internal instructions** (like a pair of gloves) or **"hidden variables"**—that we just haven't discovered yet—that dictate the particles' behavior from the start that fixes the orientations of the spins all along

Double-Slit Experiment

- First described by Thomas Young in 1801 when making his case for the wave behavior of visible light
- **Tiny particles like electrons or photons act like waves** when no one is watching, spreading out in different directions. However, when they are **observed, they behave like solid particles, taking a single, definite path**
- Simply watching something can change how it behaves, raising interesting questions about the connection between **observation, reality, and even consciousness**
- When particles act as waves they form an interference pattern


Young's Double-Slit Experiment
Shutterstock
Light Source
Two Slit
Interference Pattern
Difraction
Explore

Interference Pattern



The Anomaly: Wave or Particle and the Fuzzy World

- The **Double-Slit Experiment** forced us to choose: Is the universe made of solid 'stuff' (Newton), or is it made of vibrating 'waves'?
- We expected to see bullets hitting a wall; instead, we saw ripples in a pond. The 'bricks' vanished, and in their place, we found waves. This is the moment we moved from the physics of **Certainty** to the physics of **Possibility**
- Mysterious way the universe behaves was highlighted

The Pioneers (The Copenhagen Interpretation)

- While Einstein was the "rebel" who kickstarted quantum theory, the **Copenhagen Interpretation** was the "government" that eventually took over
- Developed in the mid-1920s (primarily by **Niels Bohr** and **Werner Heisenberg** in Copenhagen), it became the standard way we understand the subatomic world today
- It moved physics away from Einstein’s "logical reality" and into a world of **probability and observation**

The Pioneers (The Copenhagen Interpretation)

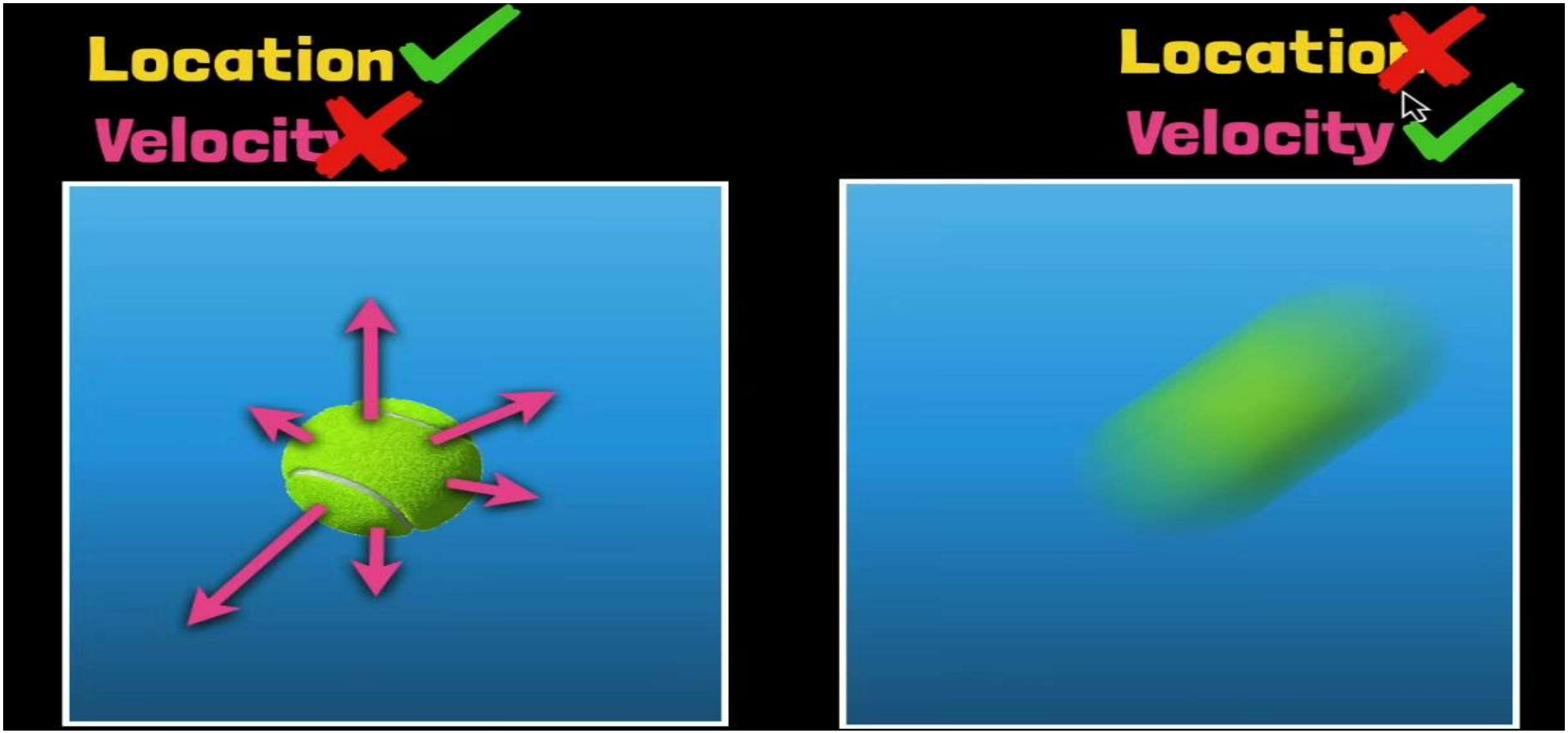
Copenhagen interpretation holds that conscious observation causes the wave function to collapse into a single reality

Heisenberg: UP- You can’t know where a particle is and where it’s going at the same time

Schrödinger: Introduce the **Wave Function** and his famous cat

Niels Bohr (1885-1962)**:** The father of the first quantum model. The act of **measurement** changes reality

Werner Heisenberg’s Uncertainty Principle

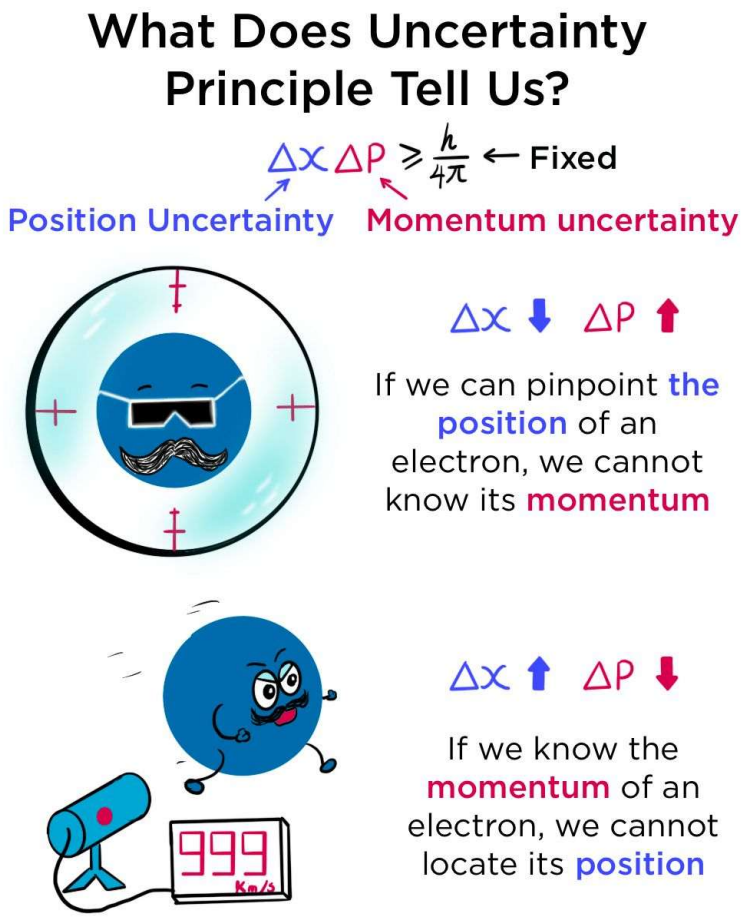


Werner Heisenberg's Uncertainty Principle

- The universe has a built-in speed limit on knowing a particle. You can know **where** the particle is, OR you can know **how fast** it's going, but you can never know both at the same time
- Everything in the universe **behaves like both a particle and a wave at the same time**, therefore, the exact position and exact speed of an object have no meaning
- Probability is intrinsic/fundamental to the description of nature
- There are **limitations of measurement**

Werner Heisenberg's Uncertainty Principle

- When attempting to observe subatomic particles, the **experimental apparatus inevitably influences their trajectories**
- A device (apparatus) must project photons onto the particles. However, this interaction disturbs the subatomic particles due to their comparable sizes. Consequently, it becomes impossible to observe subatomic particles without altering their trajectories

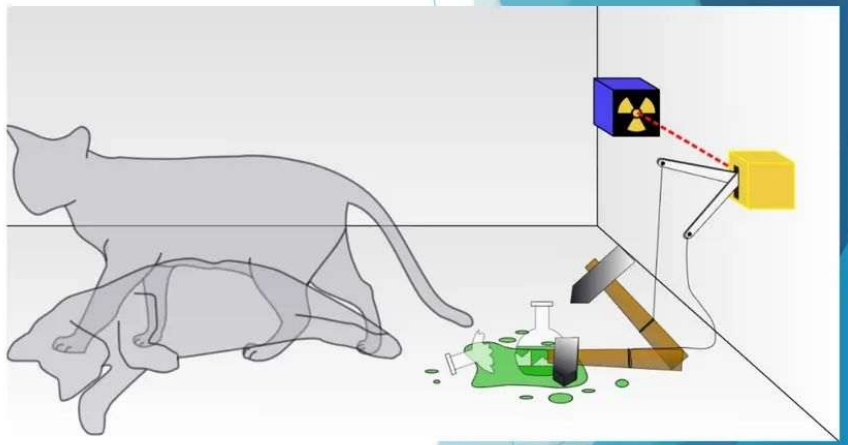


- An electron isn't a solid "dot" orbiting a nucleus like a planet. Instead, it is a **cloud of probability.** It exists in a "Superposition"—meaning it is technically in many places at once until someone looks at it

The Schrodinger's Cat Paradox

Schrodinger's cat paradox is a thought experiment proposed by Erwin Schrödinger to illustrate the strange nature of quantum mechanics.

A cat is placed in a sealed box with a device that could kill it, triggered by the decay of a radioactive atom. Until the box is opened, the cat is both alive and dead, existing in a superposition of states. This paradox highlights the strange nature of quantum superposition, where particles can exist in multiple states at the same time.



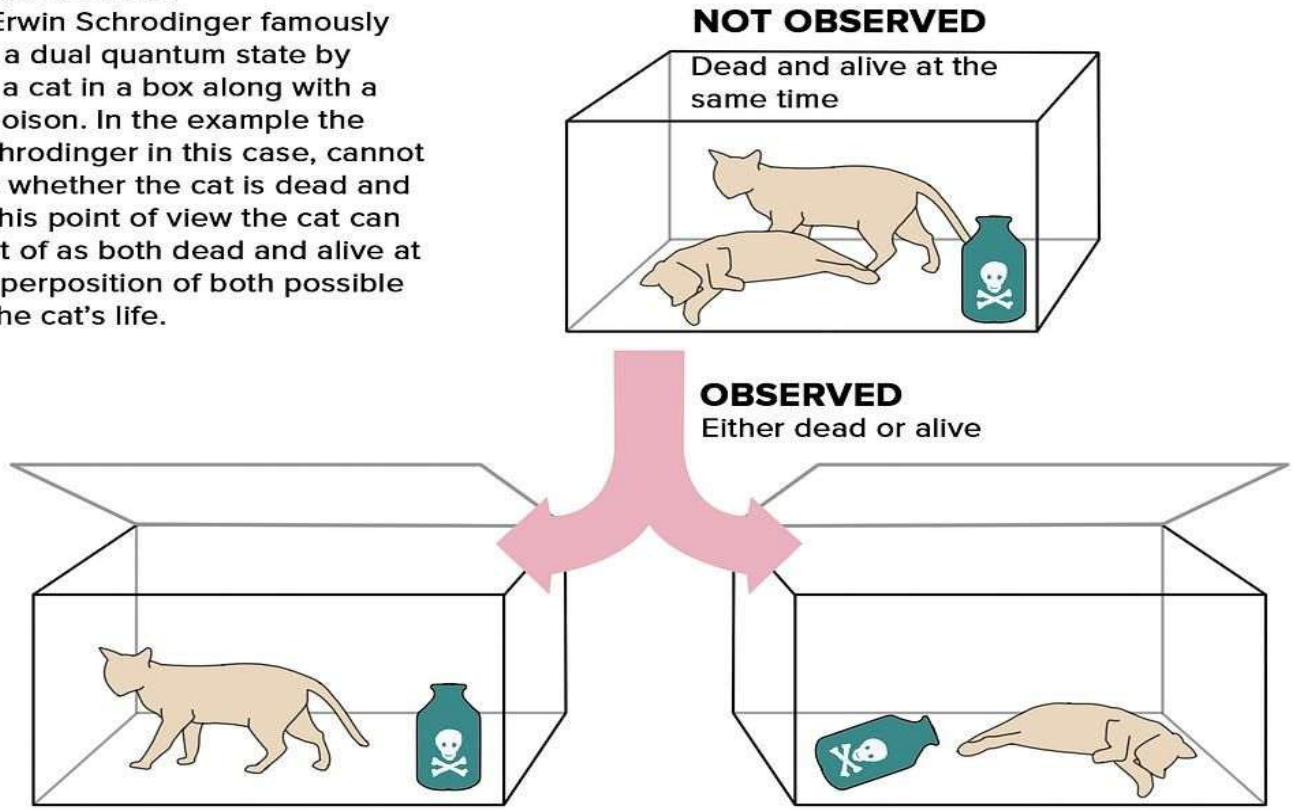
Cat

Paradox

Super position

QUANTUM STATE

Physicist Erwin Schrodinger famously illustrated a dual quantum state by imagining a cat in a box along with a bottle of poison. In the example the viewer, Schrodinger in this case, cannot determine whether the cat is dead and thus from his point of view the cat can be thought of as both dead and alive at once, a superposition of both possible states of the cat's life.



Erwin Schrödinger-the Wave Nature of Matter

- **Objects have wave-like behavior** described by wave functions; these waves aren't localized but instead **take up all of space** until you look for a particle
- The particle, before that, is a collection of probability **waves that theoretically extend out to the entire universe**
- This is not a limitation of our measuring devices. The universe itself doesn’t know the answer

Erwin Schrödinger-the Wave Nature of Matter

- **Schrödinger's Wave Equation(1926)**. If Newton's laws describe how a planet moves, Schrödinger's equation describes how a quantum particle "exists." Instead of saying an electron is a "point" at a specific location, his math treats the electron as a **Wave Function**. This equation doesn't tell you exactly where the electron is but tells you the **probability** of where it might be
- **From Orbits to "Clouds"**- Because of this, we stopped drawing **electrons** as "dots on a circle" and started drawing them as **orbitals** (probability clouds). These clouds represent the 3D spaces where an electron is 90% likely to be found

Superposition of Two States

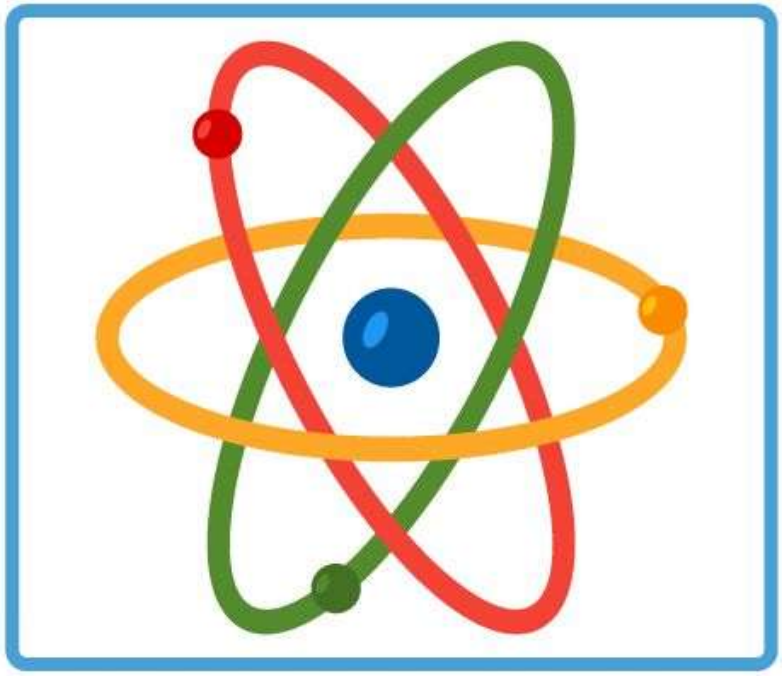
- A quantum **particles can exist in a no. of states at once** as a combination of states (in a superposition of being in multiple locations) until it is measured
- There are **infinite realities** and the ones that we experience are the ones that we have collapsed into place
- **Measurement Collapse** of a "quantum coin" forces it to "land," instantly collapsing the superposition into a definite 0 or 1

The Main Difference: How they "Draw" Reality

Together, they proved that the universe is not made of "things," but of **information and possibilities.** **Heisenberg** tells us we are limited observers and **Schrödinger** tells us that reality is fluid until we step in to witness it

Feature	**Heisenberg (Matrix Mechanics)**	**Schrödinger (Wave Mechanics)**
Perspective	Focused on **Particles**	Focused on **Waves**
Visual	Reality is a "flicker" of points you can't quite catch	Reality is a "cloud" of vibrating energy
The Result	We are limited by our **Measurement**	We are limited by the **Nature of the Wave**

DO NOT OBSERVE



Can Observing Something
Change It's Outcome?

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Is Observation a Neutral Act ?
The measurement problem in QM: Observer Effect

- The problem is that we only observe particles, not waves
- Is what we observe, measurable?
- Measurement is an interaction of the quantum object with some kind of measuring device where an **irreversible exchange of energy** happens; whenever a measurement is made, the **wave collapses and becomes a localized wave, or particle**
- This “wave collapse” is inexplicable and we can never directly see this quantum world

Observer Effect

Great divide between Classical view and Quantum view of Physics and Philosophy

- **Classical assumption: We can separate the observer and the observed a**nd everything is an object with no life, no organizing capacity, no subject, and no agency of its own. Humans can master the nature
- **QP assumption:** the observer (a measuring device or detector) interacts with the observed (a particle like an electron or photon), forcing it from a wave-like superposition of possibilities into a single, definite state. **The mind/tool isn't just watching; it's *creating* the result**

The Observer and the Observed

Descartes (1644)

- **"Cogito, Ergo Sum"** (I think, therefore I am)-

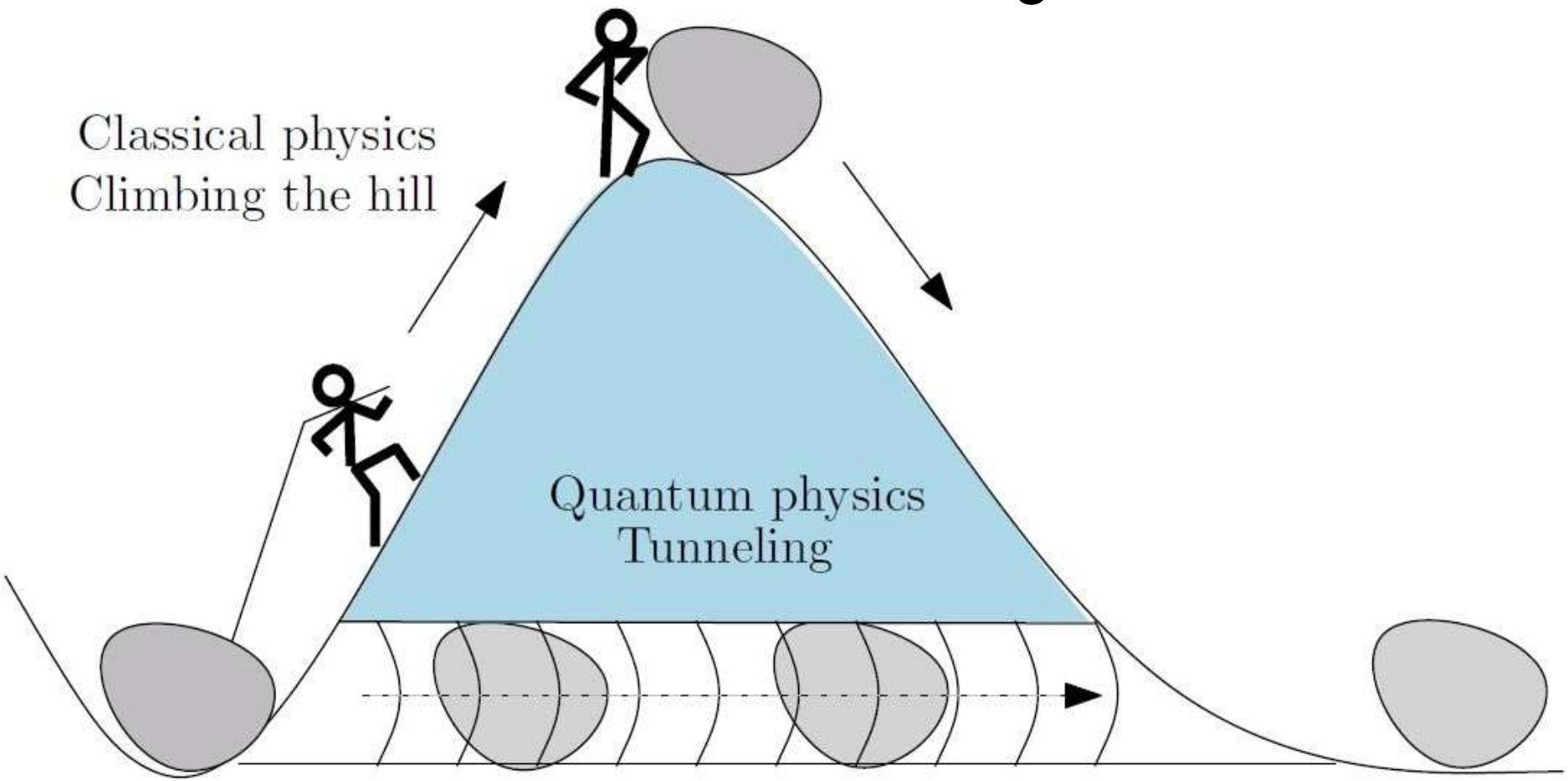
  mind vs body

- Determinism
- Consciousness is a silent observer of a "dead" material world

Quantum Mechanics (1920s+)

- **"Observo, Ergo Est"** (I observe, therefore it is) mind and atoms are two sides of same coin
- Probability
- Consciousness is a **participant** that "collapses" the wave function into reality

Quantum Tunnelling



Quantum Tunnelling

- The wavefunction of a **particle exists in all of the space**, in the entire universe; this **probability is non-zero**
- In the quantum world, particles can **pass through impenetrable, a potential energy barriers** that they classically shouldn't be able to overcome
- There is a non-zero chance that your **atoms may dissolve** and reappear up on the other side of the wall
- It's due to the wavelike nature of particles, which allows them to simultaneously exist on the other side of an impenetrable barrier
- Video How Quantum Tunneling Works. It's the Reason Life Exists! - YouTube

Conclusion

- **The "Holistic" Defense:** atoms exhibit holistic properties and perhaps some primitive relationship to consciousness. Particles are a **single, unified entity yet not "local" or "separate"** until we measure them
- The universe is fundamentally **interconnected**. The measurement of Particle A and the state of Particle B are part of one phenomenon
- We **can never come to the absolute truth** using imperfect instruments of perception for human intelligence only works on the platform of time and space

Conclusion

- Quantum physics also brought the idea of *probability* into the heart of physical laws; quantum physics equations only tells us the chances of different results
- Everything is actually exploring **all possible paths, all at once**
- **Free will does exist?? Quantum leap??**

Criticisms & Cautions

Our current physics does not come to terms with life i.e. living systems and consciousness. We need experimental tools to map that out. Consciousness is something fundamental to the fabric of reality- matter, energy, space, and time come out of that. And what if we could rewrite all the laws of physics to be compatible with that framework? **Thus we can build upon the beautiful physics that has happened in the last hundred years! There are tremendous capabilities to have a participatory universe**.

A Harvard-MIT-Stanford trained physicist, physician, inventor, and a world renowned scientist

Thank You

Books

1. Physics of the impossible by Michio Kaku
2. The Big Picture by Sean Carroll
3. Tao of Physics by Fritjof Capra
4. Quantum Physics For Dummies by by Steven Holzner

Articles

1. Superposition Explained: The Spinning Coin Analogy | by Servifyspheresolutions | SSS Quantum | Medium
2. How Does Quantum Mechanics Meet Up With Classical Physics? - UMD Physics
3. Classical Physics, Quantum Mechanics, Relativity, Super String Theory And Mediation - Mediate.com
4. Einstein–Podolsky–Rosen paradox - Wikipedia
5. The Quantum Leap's Beginner Guide to the "Observer Effect" | by Russ Fein | Medium

Youtube Videos

1. Decoding the Universe: Quantum | Full Documentary | NOVA | PBS
2. The SIMPLEST Explanation of QUANTUM MECHANICS in the Universe!