Schrödinger's Cat

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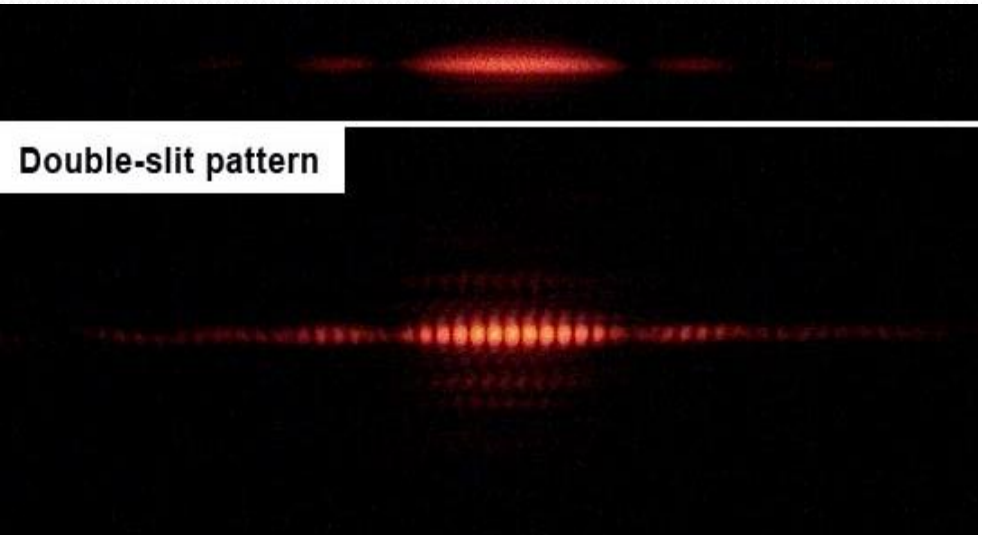
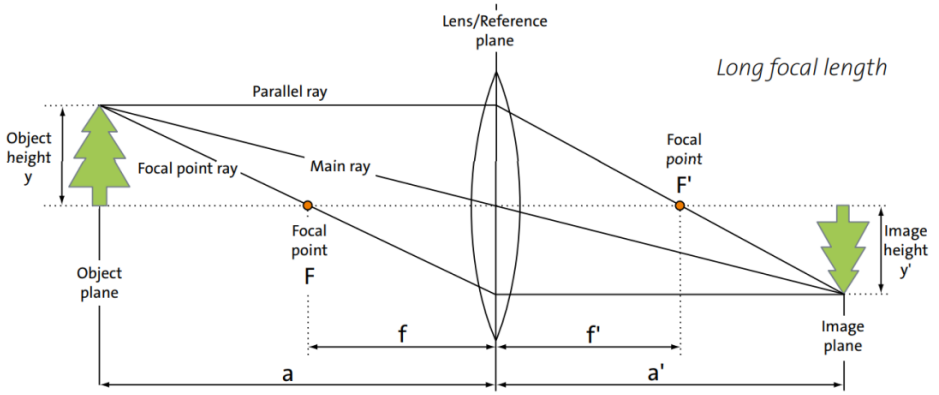
Duality Paradox[1]

- Democritus, Euclid (5-3rd century BC) > particle
- René Decartes (1630) > wave in „luminiferous aether”
- Isaac Newton (1670) > corpuscular theory of light
- Christiaan Huygens, Augustin-Jean Fresnel > wave
- Thomas Young (1801) > double slit experiment
- James Clerk Maxwell > electromagnetic waves
- Alexandre-Edmond Becquerel (1839) > photovoltaic effect[2]

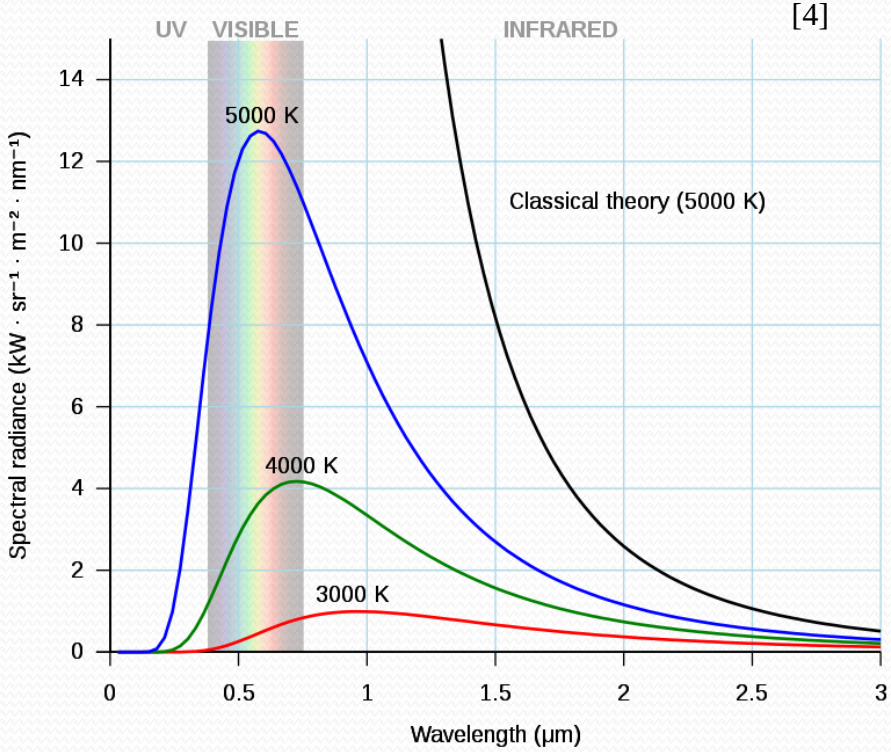




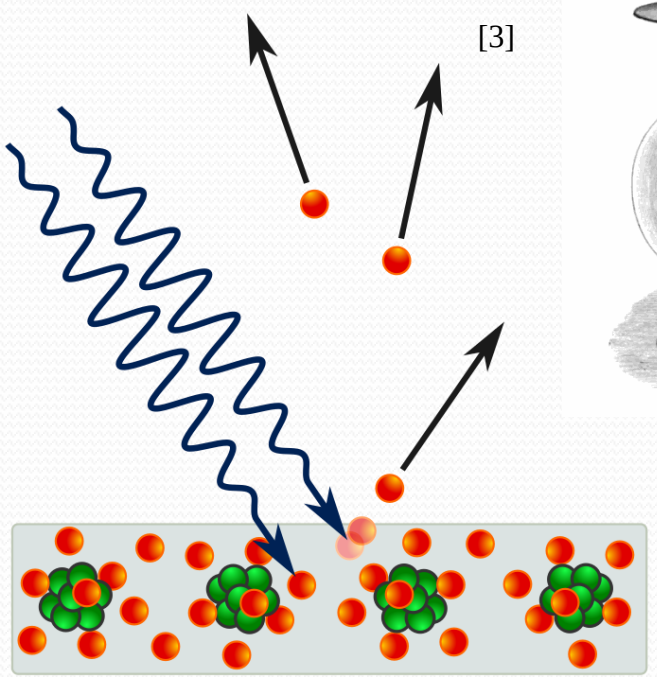
Duality Paradox

- Heinrich Hertz (1887) > photoelectric effect [3]
- Max Planck (1901) > black body radiation, UV catastrophe
- Albert Einstein (1905) > „On a Heuristic Viewpoint Concerning the Production and Transformation of Light„
- Robert Andrews Millikan (1914) > experimental verification

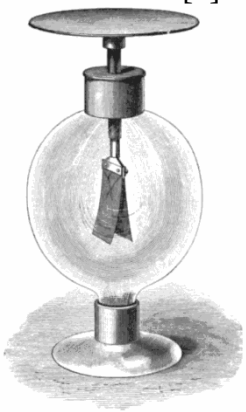
[4]



[3]



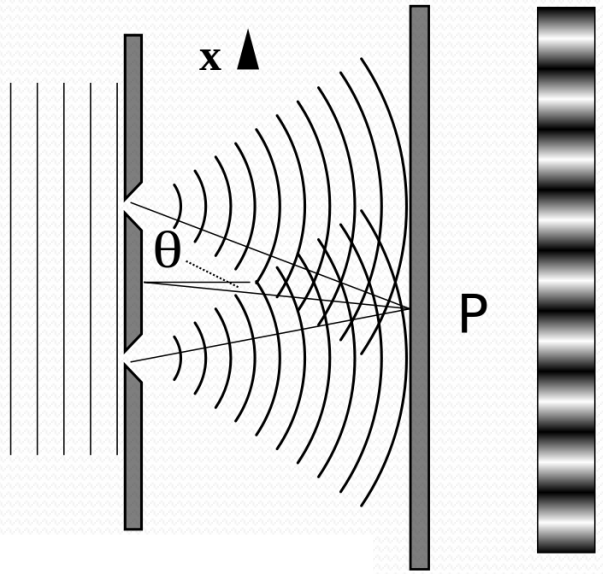
[2]



The Double Slit Experiment [5]

Both slits open:

- Interference pattern

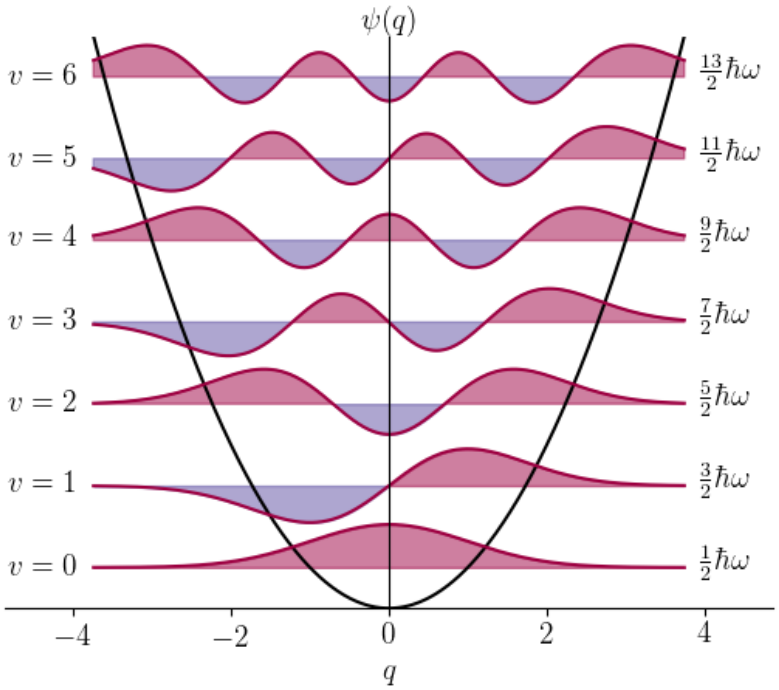


One slit covered:

- Only 1 spot

Single photon/e$^-$ case:

- Interference pattern



Upon „observation”:

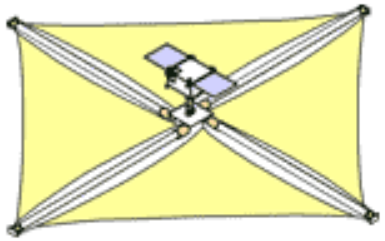
- 2 spots

The Observer Effect[6]

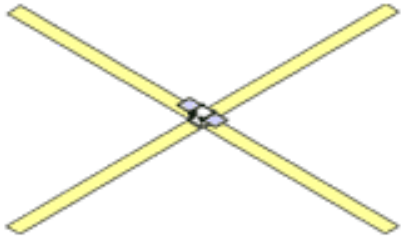
The act of preforming a measurement (/quasi-measurement) can only occur through a physical interaction with the measured system, which inevitably changes the state of that system.

The measurement result is directly influenced by the type of measurement performed.

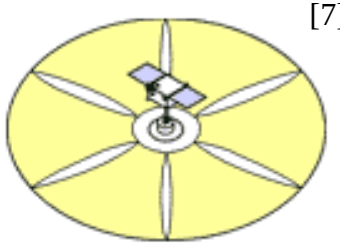
[7]



Square Sail (not to scale)

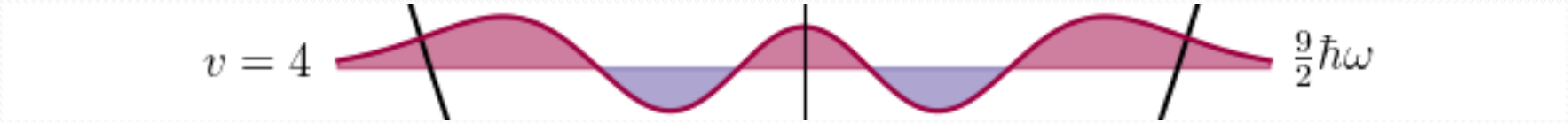


Heliogyro (not to scale)



Spinning Disk Sail (not to scale)

$$\sigma_x \sigma_p \geq \frac{\hbar}{2}$$

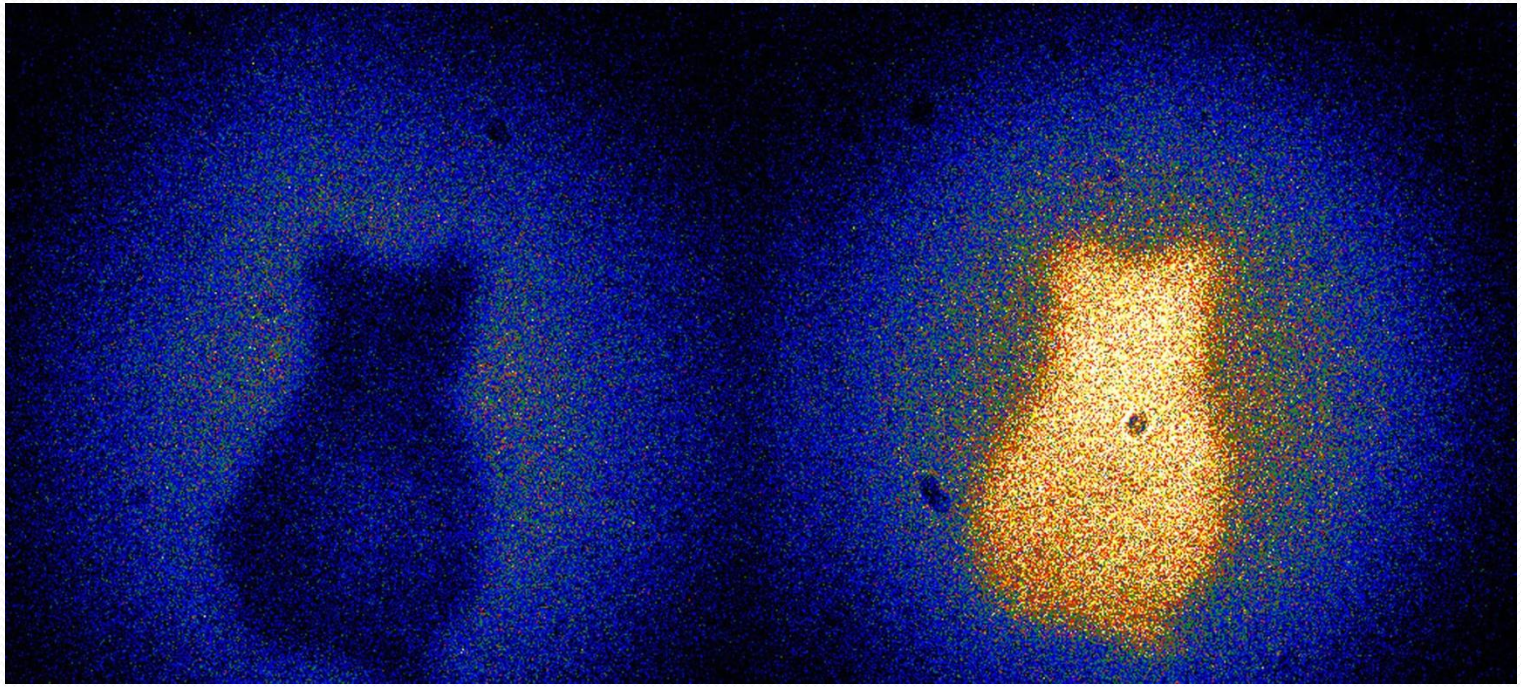


Quantum Entanglement [8]

It occurs, when multiple objects can not be described independently of the state(s) of other object(s).

Examples: spins of entangled particles

entangled laser beams



„spooky action from a distance”

EPR Paradox [9,10]

Albert Einstein - Boris Podolsky - Nathan Rosen (1935): "Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?„

No FTL effect.

Measure X_A property. Predict X_B property.

A  B

The EPR Criterion of Reality:

„If, without in any way disturbing a system, we can predict with certainty the value of a physical quantity, then there exists an **element of reality** corresponding to that quantity"

EPR Paradox[11]

EINSTEIN ATTACKS QUANTUM THEORY

Scientist and Two Colleagues
Find It Is Not 'Complete'
Even Though 'Correct.'

SEE FULLER ONE POSSIBLE

Believe a Whole Description of
'the Physical Reality' Can Be
Provided Eventually.

The Absurdity of Superpositions[1]

- An unstable keg of gunpowder, should appear both exploded and not exploded, in it's wavefunction.
- This wavefunction only collapses upon interaction, according to the Copenhagen interpretation.

$$\Psi = \Psi(\ \ ) + \Psi(\ \ ) [+...]$$

Both Einstein and Schrödinger has found this view too absurd, too indeterministic. The EPR article supported „local realism" instead.[13]

Schrödinger's Cat: The Original Proposal[1]

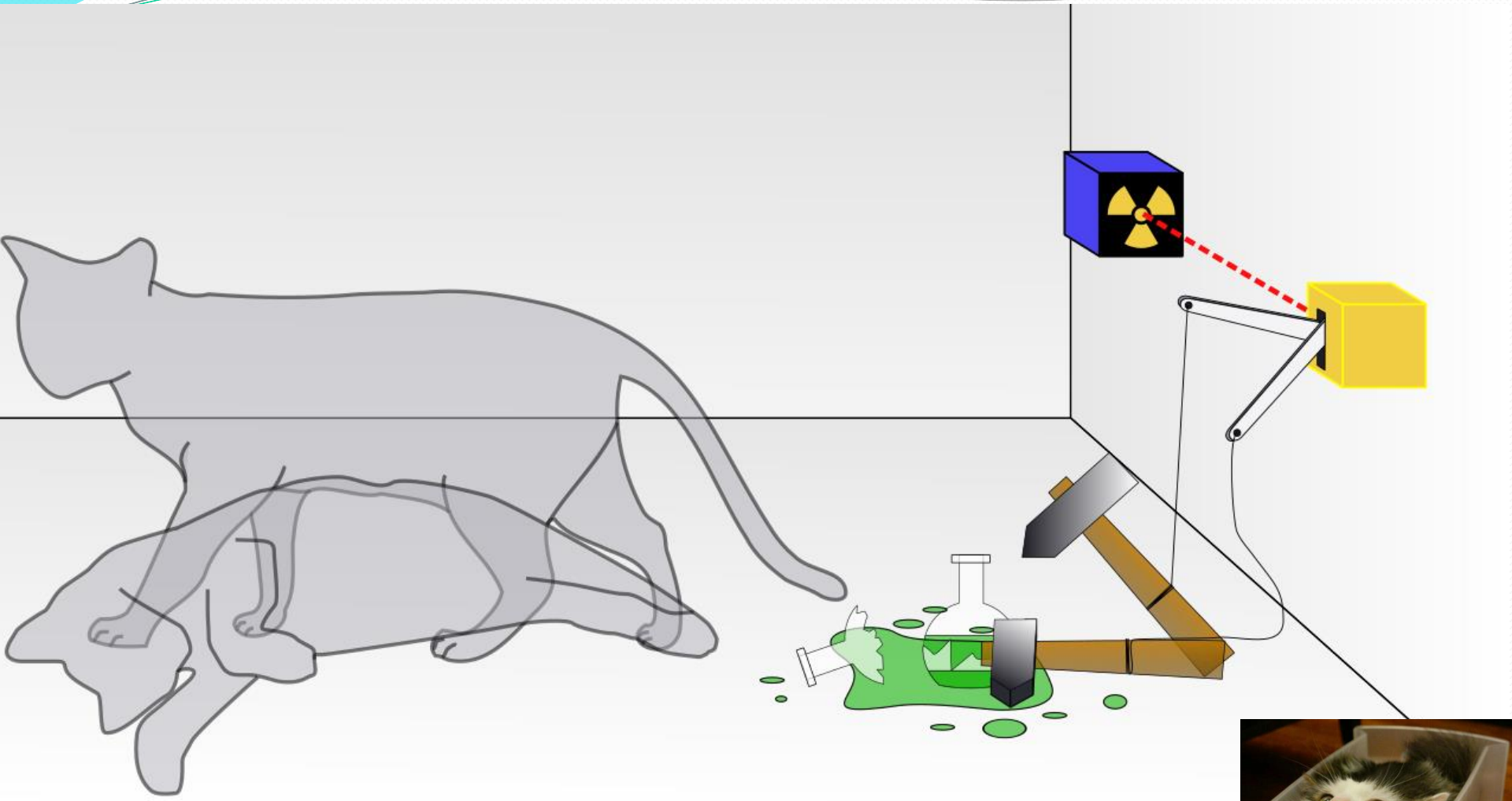
„One can even set up quite ridiculous cases. A **cat** is penned up in a steel chamber, along with the following device (which must be secured against direct interference by the cat): in **a Geiger counter**, there is a tiny bit of **radioactive substance**, so small, that perhaps in the course of the hour one of the atoms decays, but also, with equal probability, perhaps none; if it happens, the counter tube discharges and through **a relay** releases a **hammer** that shatters a **small flask of hydrocyanic acid**. If one has left this entire system to itself for an hour, one would say that the cat still lives if meanwhile no atom has decayed. The first atomic decay would have poisoned it. The psi-function of the entire system would express this by having in it the living and dead cat (pardon the expression) mixed or smeared out in equal parts.

It is typical of these cases that an indeterminacy originally restricted to the atomic domain becomes transformed into macroscopic indeterminacy, which can then be resolved by direct observation. That prevents us from so naïvely accepting as valid a "blurred model" for representing reality. In itself, it would not embody anything unclear or contradictory. There is a difference between a shaky or out-of-focus photograph and a snapshot of clouds and fog banks."

Schrödinger's Cat: Einstein's Reply [1] (1950)

„You are the only contemporary physicist, besides Laue, who sees that one cannot get around the assumption of reality, if only one is honest. Most of them simply do not see what sort of risky game they are playing with reality—reality as something independent of what is experimentally established. Their interpretation is, however, refuted most elegantly by your system of radioactive atom + amplifier + charge of gun powder + cat in a box, in which the psi-function of the system contains both the cat alive and blown to bits. Nobody really doubts that the presence or absence of the cat is something independent of the act of observation."

Schrödinger's Cat[1]



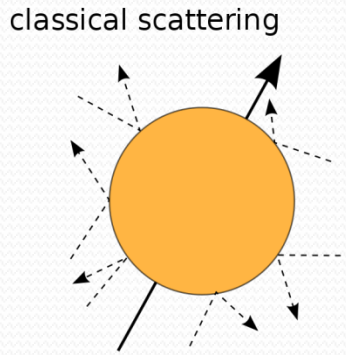
Schrödinger's Cat

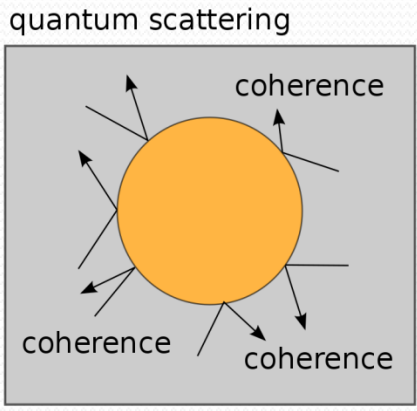
- From which point does a superposition occur?
- What are the boundaries of the quantum theory?
- What qualifies as an observer?
- Does consciousness bear any physical meanig?
- How does a superposition collapse into a single state?
- When does the superposition and entanglement end?
- Is entanglement even a finite phenomenon?
- What is the correct interpretation of quantum mechanics?

The Copenhagen Interpretation[1,13]

It is the most commonly accepted interpretation of quantum mechanics to date.

- A superposition of states collapses on observation into a single classical state.
- After a decoherence time the superposition collapses, before any observation takes place. (Niels Bohr)
- OR the collapse is just an „update” for the statistical data. (Werner Heisenberg)

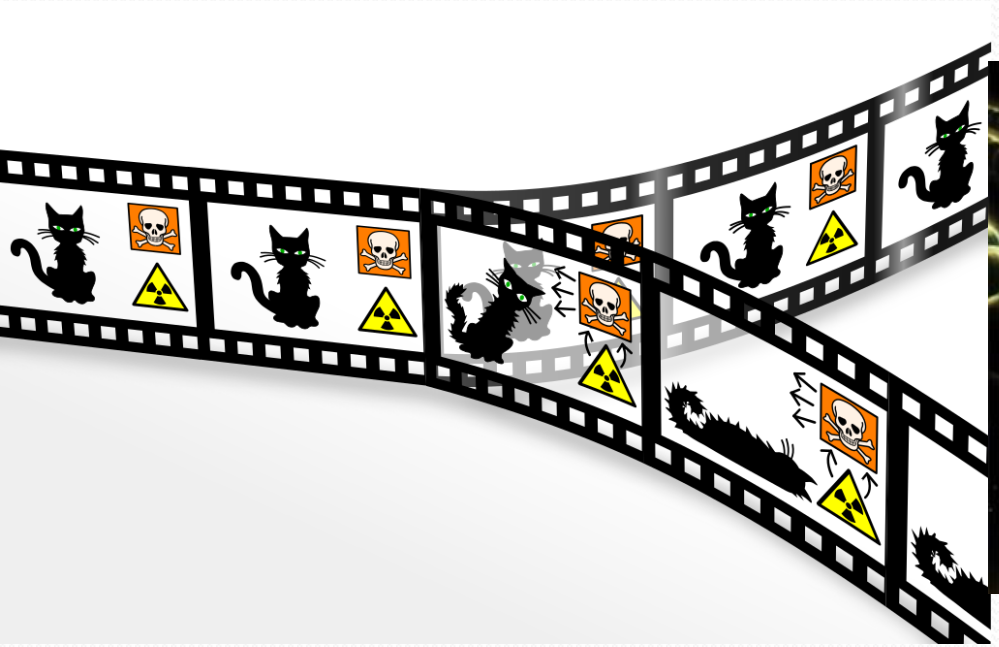




The Many-Worlds Interpretation[1,14]

Popularized by Hugh Everett in ~1957.

- Only one eternal superpostion exists for the universe.
- The possible states undergo decoherence, and can no longer interact with each other.
- Each states continues it’s „consistent history”.



The Ensemble Interpretation[1,15]

- This theory denies the existence of superpositions.
- The statistics only apply for many similar measurements.
- This way the cat-in-a-box experiment is trivialized.

The Relational Interpretation [1,16]

- It postulates that all quantum mechanically governed systems act as observers.
- There may be differences between the observations.

Experiment

Observer 1

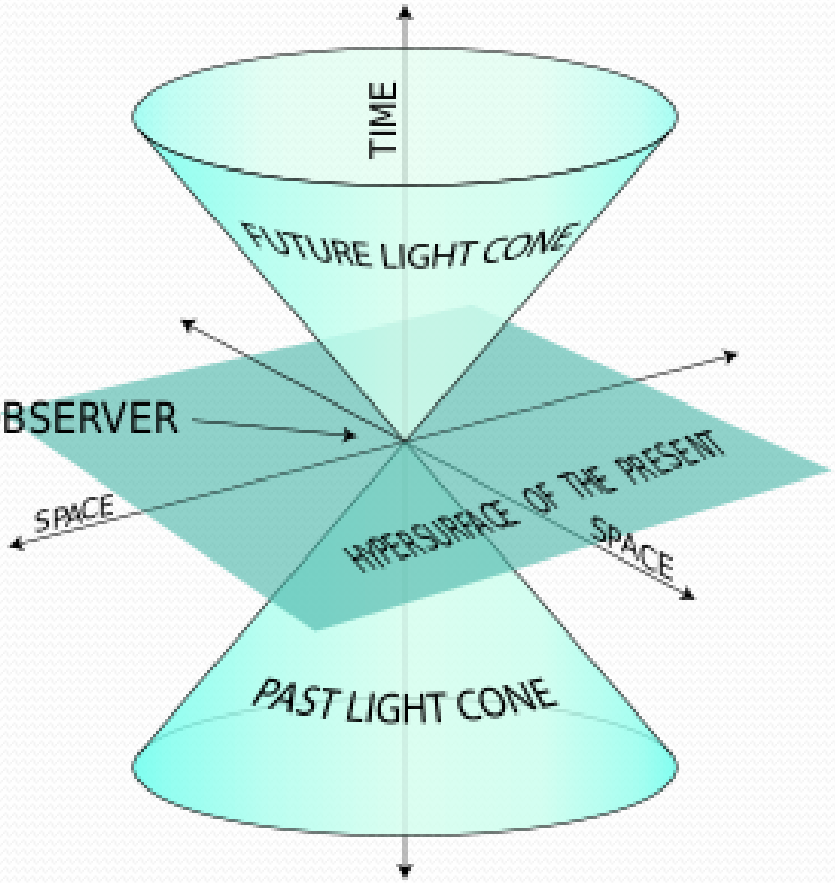
Observer 2

The Objective Collapse Theory [1,17]

- The superposition will collapse after it reaches an arbitrary threshold in some measure.
- Currently quantum mechanics does not allow (/ include) a superposition collapse by time evolution.

The Transactional Interpretation [1,18]

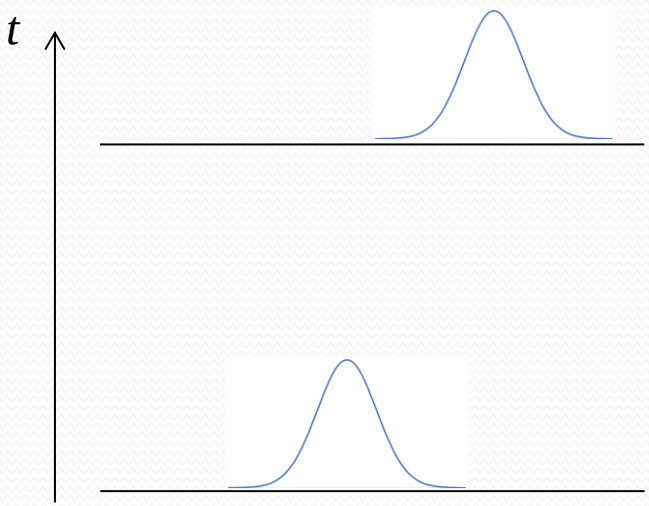
- Advanced waves are emitted both forwards and backwards in time, that are interacting, while the present experiment acting as the observer.
- There is no superposition, the cat is always in only one classical state.

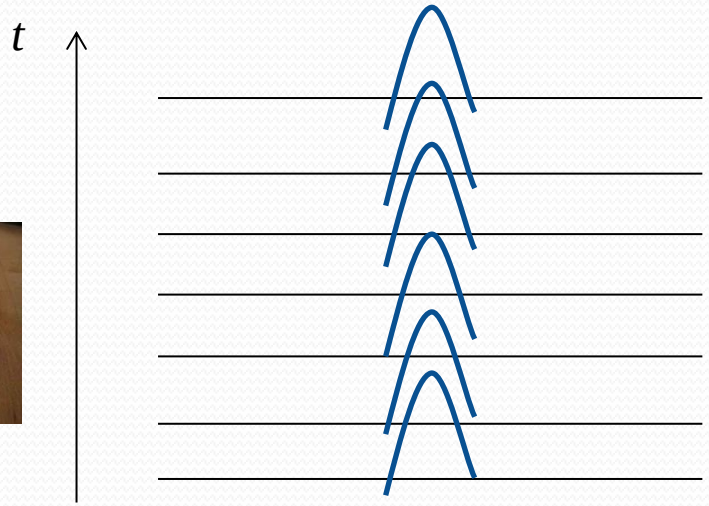


The Zeno Effects / Turing Paradox [1,19]

Observation frequency can alter the lifetime of the observed state. „A system cannot change while you are watching it.”

- Very frequent, short observations, can slow the time evolution.
- Less frequent, observations can accelerate the time evolution.





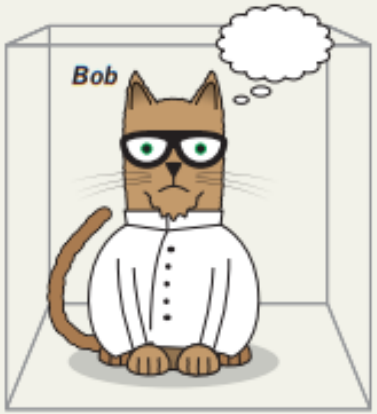
New Theories

[20,21,22,23]

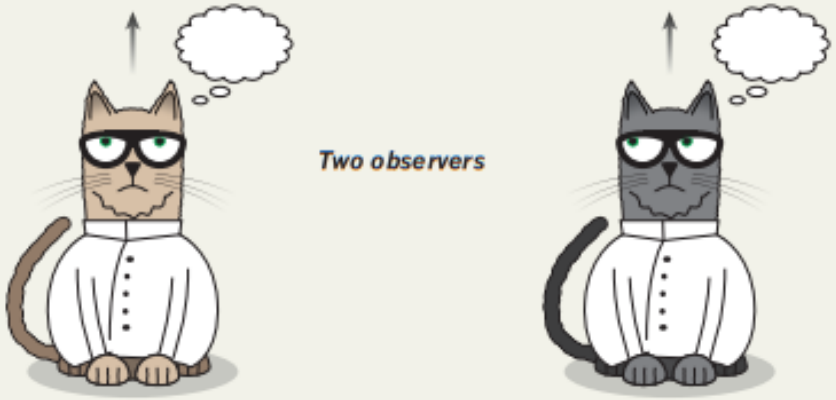
NEW CATS IN TOWN

Physicists have devised a variation of the iconic Schrödinger's cat thought experiment that involves several players who understand quantum theory. But surprisingly, using the standard interpretation of quantum mechanics, the observers sometimes seem to come to different conclusions about a particular event — suggesting that the interpretation contradicts itself for complex systems.

Alice tosses a coin and, using her knowledge of quantum physics, sends a quantum message to Bob.



Using his knowledge of quantum theory, Bob can detect Alice's message and guess the result of her coin toss.



When the two observers open their boxes, in some situations they can conclude with certainty how the coin landed — but their conclusions are different. This means that the standard interpretation of quantum theory gives an inconsistent description of reality.

Lessons

- Superposition
- Interference
- Entanglement
- Decoherence (at scale)

Quantum computing, Quatum mechanics, Teaching methods

Trivia [1,24,25]

Sources

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