(SFI5905) INTERACTION BETWEEN RADIATION AND MATTER

SCHRÖDINGER'S CAT

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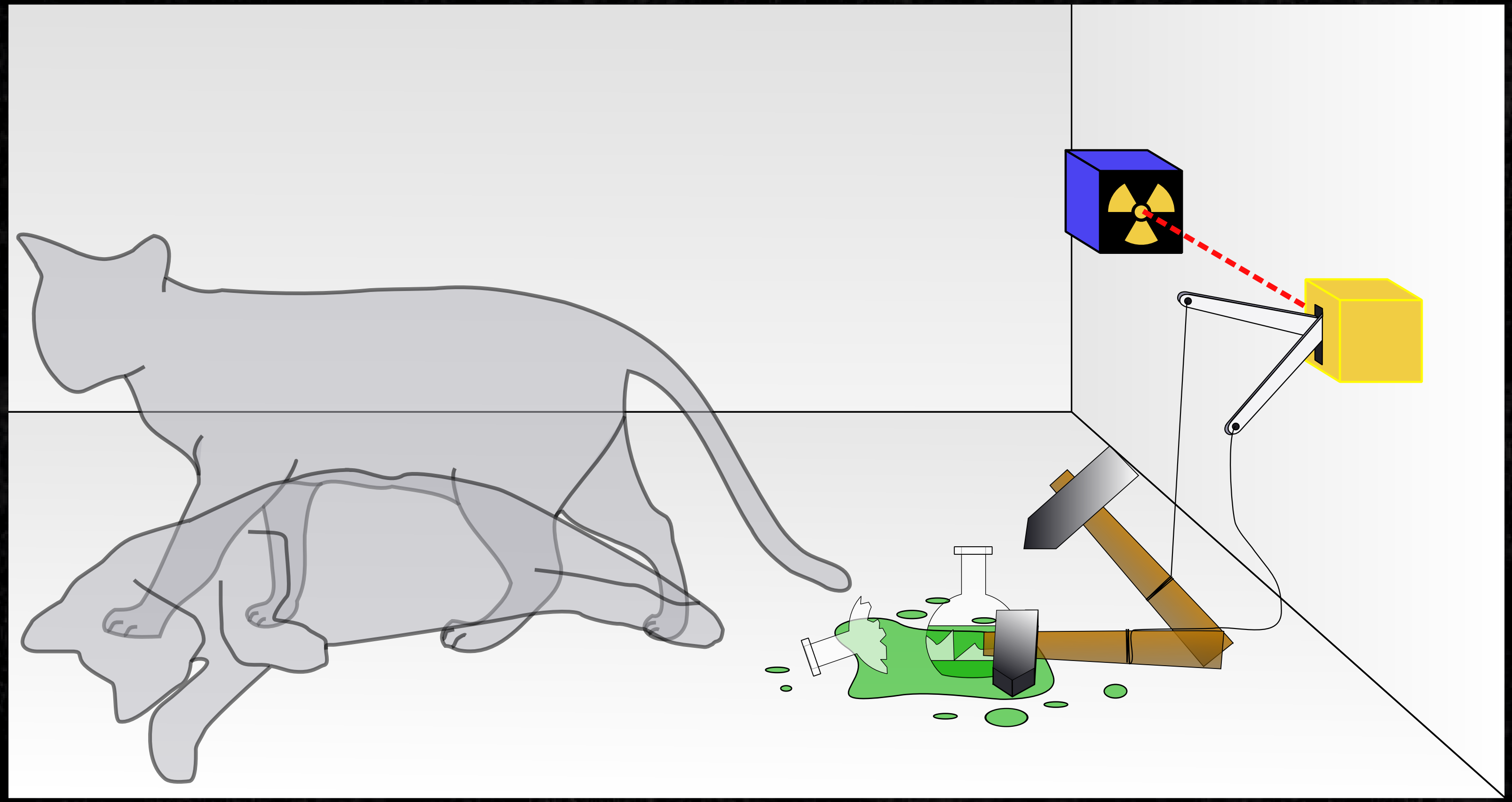
SUMMARY

1. INTRODUCTION



“A cat is placed in a steel chamber, together with the following hellish contraption (which must be protected against direct interference by the cat): In a Geiger counter there is a tiny amount of radioactive substance, so tiny that maybe within an hour one of the atoms decays, but equally probably none of them decays. If one decays then the counter triggers and via a relay activates a little hammer which breaks a container of cyanide"

1. INTRODUCTION

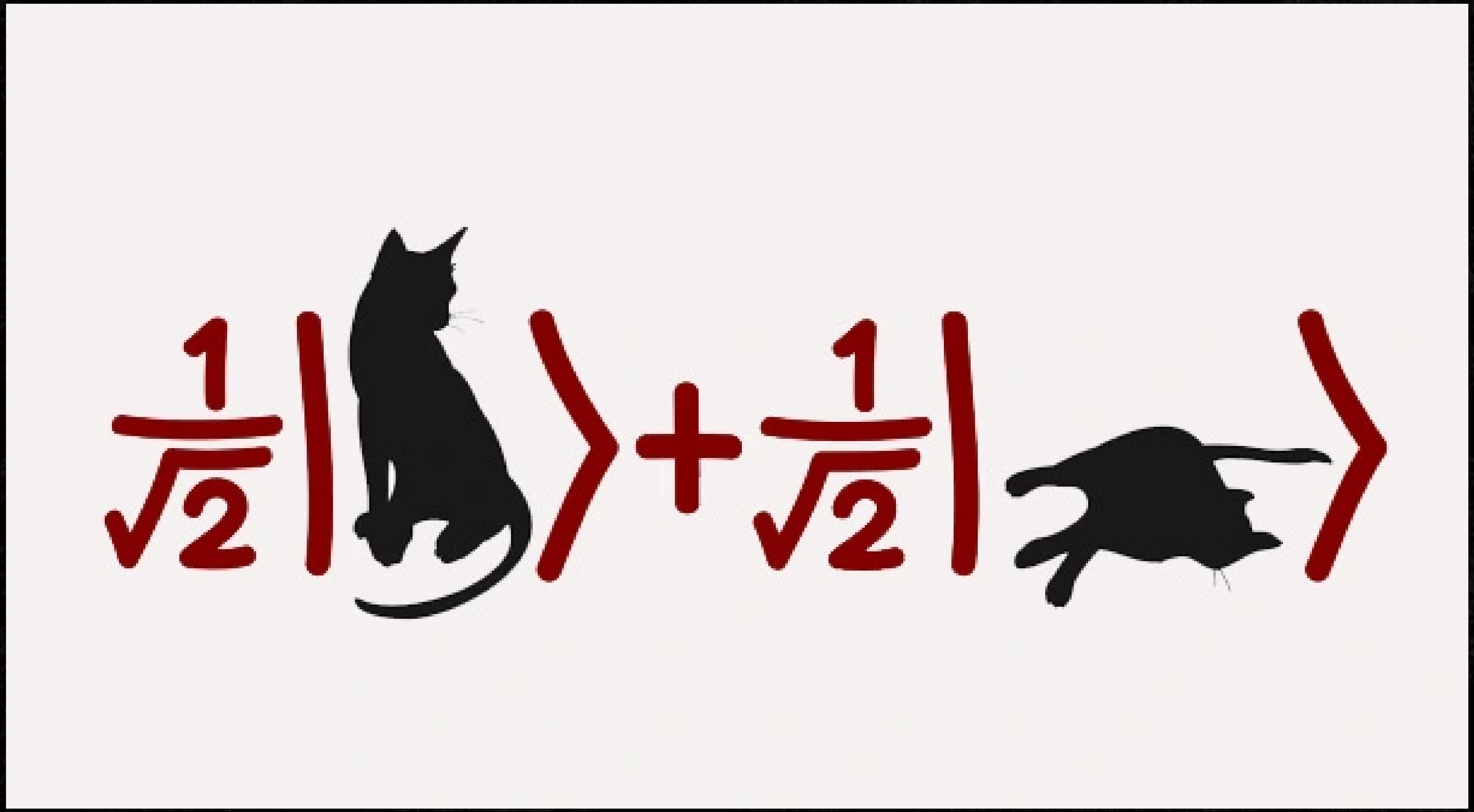
- Initial state (t=0):

$$|\psi(0)\rangle = |undecayed\rangle \otimes |untriggered\rangle \otimes |unactivated\rangle \otimes |unbroken\rangle \otimes |alive\rangle$$

- Cat state at T = 1 hour:

$$|\psi(T)\rangle = \frac{1}{\sqrt{2}} |undecayed\rangle \otimes |untriggered\rangle \otimes |unactivated\rangle \otimes |unbroken\rangle \otimes |alive\rangle + \frac{1}{\sqrt{2}} |decayed\rangle \otimes |triggered\rangle \otimes |activated\rangle \otimes |broken\rangle \otimes |dead\rangle$$

1. INTRODUCTION



1. INTRODUCTION

Copenhagen Interpretation

- Quantum Mechanics is a logical continuation of Classical Mechanics - Principle of Correspondence (Bohr)
- Quantum Mechanics answers statistical questions, not concerning to individual motions and evolutions(Born)
- We cannot describe what happens between observations, what we observe is not nature itself but nature subject to our method of questioning (Heisenberg)
- Observations not only disturb what has to be measured, they produce it (Jordan)

1. INTRODUCTION

Copenhagen Interpretation - Schrödinger's Cat

THE ACT OF OBSERVATION FORCES THE CAT TO MAKE A DECISION (ALIVE OR DEAD) - ARE WE MURDERING THE CAT JUST BY LOOKING AT HIS STATE?

HOW CAN WE DEFINE THE CONSCIOUSNESS OF THE MEASURE AND THE EXACT MOMENT THAT IT HAS SOME EFFECT ON THE STATE OF THE CAT?

2. QUANTUM MECHANICS IS INCOMPLETE AND THERE IS COLLAPSE

2.1. Von Neumann's Infinite Regress/Chain

- System *S* and measurement apparatus *M* (both considered as quantum systems)
- System *S* initially at a superposition of states - Schrödinger Equations that the whole system *S+M* reaches a linear superposition after the interaction (quantum entanglement)
- If we take a infinity number of measurement apparatus *M'*, *M''*,..., the linearity of Schrödinger's equation predicts a infinite chain of superpositions
- Von Neumman: linear superpositions somehow resolve themselves before they reach the macroscopic world (we always see a single result and not a superposition of results)

COLLAPSE POSTULATE

CONSCIUOSNESS?

2. QUANTUM MECHANICS IS INCOMPLETE AND THERE IS COLLAPSE

2.2. Spontaneous Localization (SL) and Continuous Spontaneous Localization (CSL)

SL Model

- Extended states of matter spontaneously collapse to localized states of size a ≈ 10^-5 cm
- In the SL model, a extended state can spontaneously localize and the probability of such localization agrees with Born's statistical interpretation of the wavefunction:

$$\int d^3x |\psi(x) g(x - \overline{x})|^2$$

- The wavefunction spontaneously collapses at a rate of once in about 300 milions years on average for a single particle

2. QUANTUM MECHANICS IS INCOMPLETE AND THERE IS COLLAPSE

2.2. Spontaneous Localization (SL) and Continuous Spontaneous Localization (CSL)

SL Model

- If we consider a macroscopic device (like a pointer), it contains many particles (≈ 10^22) and we can take one of its particles in a superposition of two orthogonal positions separated by a distance $L \gg a$. The initial state is:

$$|\psi(0)\rangle = \frac{1}{\sqrt{2}}[|0\rangle + |L\rangle]$$

2. QUANTUM MECHANICS IS INCOMPLETE AND THERE IS COLLAPSE

2.2. Spontaneous Localization (SL) and Continuous Spontaneous Localization (CSL)

SL Model

- To encompass all particles, we can index the particles by *i*, we get:

$$|\psi(0)\rangle = \frac{1}{\sqrt{2}}\left[\bigotimes_i |\psi_0^{(i)}\rangle + \bigotimes_i |\psi_L^{(i)}\rangle\right]$$

- If one of these i-particules spontaneously localizes, its wavefunction collapses to a region of size $a \ll L$ and the new wavefunction coul overlap to a pointer on the position *0* or *L*, but not both. Considering all particles, the rate of this process would take time of microseconds

The collapse would be very quick

2. QUANTUM MECHANICS IS INCOMPLETE AND THERE IS COLLAPSE

2.2. Spontaneous Localization (SL) and Continuous Spontaneous Localization (CSL)

CSL Model

- Extended states of matter spontaneously collapse to localized states of size a ≈ 10^-5 cm
- Time evolution is continuous ratter than sudden and an operator *ρ(x, t)* represents the number of particles in a sphere of radius *a*, centered at *x* at time *t*
- The evolution of a state vector depends on *ρ(x, t)* and also on a classical field *w(x,t)*. The time evolution of a mutiparticled wavefunction is described as:

$$\frac{\partial}{\partial t}|\psi_w(t)\rangle = -\frac{i}{\hbar}H|\psi_w(t)\rangle - \frac{1}{4a^3\lambda}\int dx[w(x,t) - 2\lambda\rho(x,t)]^2|\psi_w(t)\rangle$$

2. QUANTUM MECHANICS IS INCOMPLETE AND THERE IS COLLAPSE

2.2. Spontaneous Localization (SL) and Continuous Spontaneous Localization (CSL)

CSL Model

- To exemplify the CSL model, we can take $H = 0$ and consider a measuring device with a pointer cosisting of a steel needle, $1\ cm$ long, with $2 \times 10^{-3}\ cm^2$ cross section
- The operator $\rho(x, t)$ acts in a way that for specific point of the pointer it yields the total number N of the particles in the sphere of radius a and 0 elsewhere
- In order to cancel the integral that appears in the time evolution, we must have $w(x, t) = 2\lambda N$ at the position of the undisplaced pointer and 0 elsewhere or at the position of the pointer displaced by L and 0 elsewhere
- In this case, the collapse to a position 0 or L takes a time $t \approx 10^{-18}\ s$ to occur

The collapse would be very quick

3. QUANTUM MECHANICS IS INCOMPLETE AND THERE NO IS COLLAPSE

"Hidden Variables"

- There are additional variables that do not appear directly in the wavefunction, but complete the description of the system
- There are some pre existing states and the measure does not "force" the system to make a decision, it is just a way to reveal this pre existing properties of the system
- It is a theory of statistical interpretation in wich the wavefunction determine the statistical distribution of the variables
- In this sense, the collapse is just a readjustment of probabilities: in the superposed "dead-alive" cat state, the probabilities of the cat being alive or dead are both 1/2, and when we observe or measure his state, the probabilities change to 0 (state that i not observed) and 1 (state that is observed)

3. QUANTUM MECHANICS IS INCOMPLETE AND THERE NO IS COLLAPSE

"Hidden Variables"

- Bohmian mechanics: a system of particles is described in part by its wavefunction, evolving according to Schrödinger's equation. However the wavefunction provides only a partial description of the system, the other part involves the specification of the actual position of the particles
- The wavefunction is a complex function of all possible *q* configurations of the system together with its actual configuration *Q*, defined by the actual position of the particles

Bohmian Mechanics =

Schrödinger time evolution + The "Guiding Equation"

3. QUANTUM MECHANICS IS INCOMPLETE AND THERE NO IS COLLAPSE

"Hidden Variables"

Bohmian Mechanics =

Schrödinger time evolution + The "Guiding Equation"

$$i\hbar\frac{\partial\psi}{\partial t} = H\psi$$

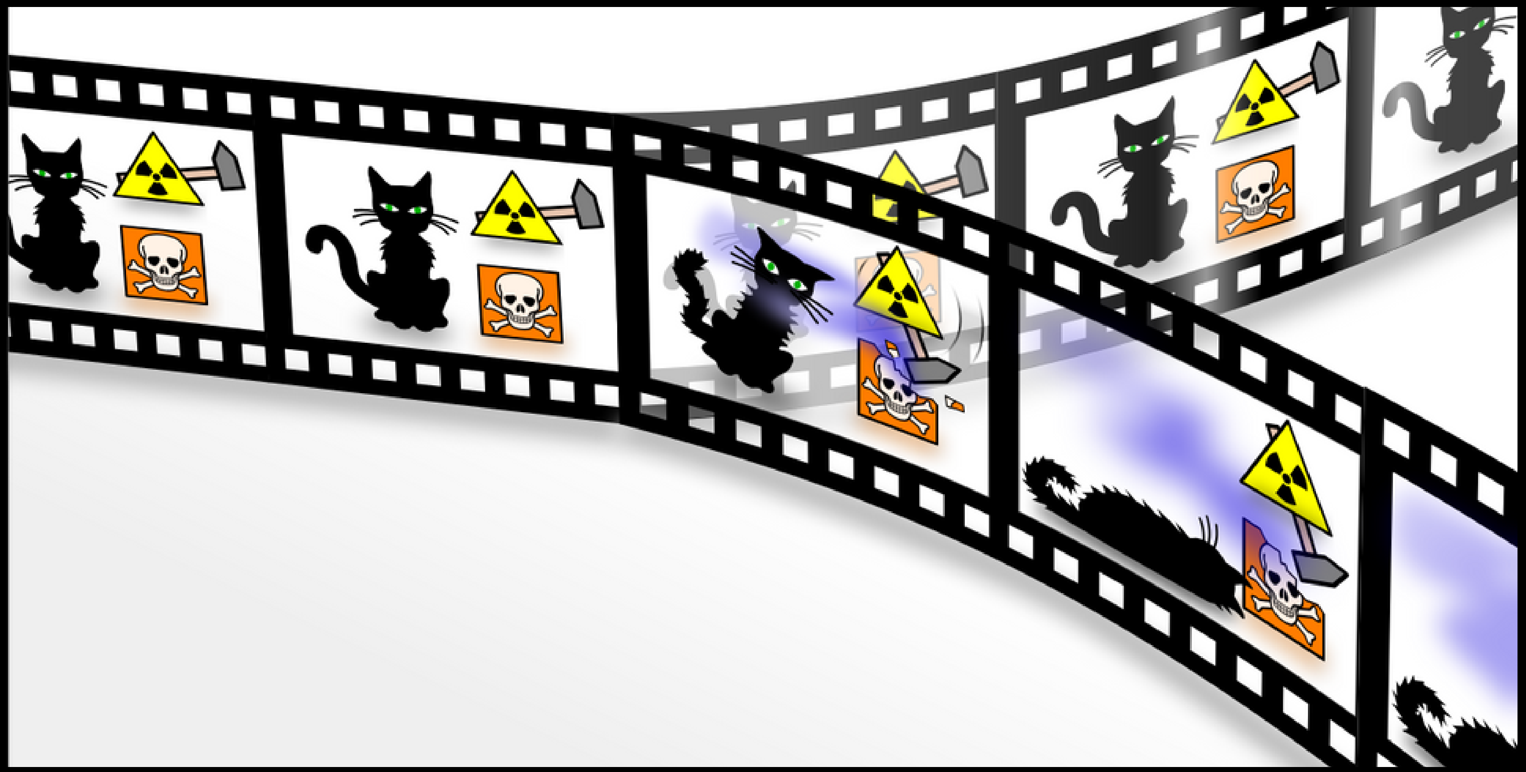
+

$$\frac{dQ_k}{dt} = \frac{\hbar}{m_k} Im \frac{\psi^* \partial_k \psi}{\psi^* \psi}(Q_1, ..., Q_N)$$

4. QUANTUM MECHANICS IS COMPLETE

"Many Worlds Interpretation"

- Considering more than one world, independent (and even paradoxical) accounts can all be real, each one representing a self-consistent state



4. QUANTUM MECHANICS IS COMPLETE

"Many Worlds Interpretation"

- We can define a set of normalized eigenstates of a observable system *S*, correlated (or measured) by a system *D*
- If the inital state of a measuring device is |do⟩ and we define |di⟩ as the measuring device indicating that the system S is in the state |si⟩, we get:

$$|s_i, d_0\rangle \rightarrow |s_i, d_i\rangle$$

4. QUANTUM MECHANICS IS COMPLETE

"Many Worlds Interpretation"

- Considering a initial superposition of states of the system *S* and unitary time evolution:

$$\sum_i c_i \left| s_i, d_0 \right\rangle \rightarrow \sum_i c_i \left| s_i, d_i \right\rangle$$

- Indexing identical *m* systems of *S* and *n* measuring devices of system *D*, we get:

$$\left| s_i^{(m)}, d_0^{(n)} \right\rangle \rightarrow \left| s_i^{(m)}, d_i^{(n)} \right\rangle$$

4. QUANTUM MECHANICS IS COMPLETE

"Many Worlds Interpretation"

- We can easily see that relative to some state |si⟩ any number os measuring devices would always agree on an account for each *i* and according to the Many Worlds Interpretation each of these accounts is real

$$\sum_i c_i \left| s_i, d_0^{(1)}, d_0^{(2)} \right\rangle \to \sum_i c_i \left| s_i, d_i^{(1)}, d_0^{(2)} \right\rangle$$
$$\to \sum_i c_i \left| s_i, d_i^{(1)}, d_i^{(2)} \right\rangle$$

4. QUANTUM MECHANICS IS COMPLETE

"Many Worlds Interpretation"

- Extending our notation considering many identical systems *S*, we can write:

$$\sum_{ij\ldots} c_i c_j \ldots |s_i^{(1)}, s_j^{(2)}, \ldots, d_0\rangle \to \sum_{ij\ldots} c_i c_j \ldots |s_i^{(1)}, s_j^{(2)}, \ldots, d_{ij\ldots}\rangle$$

- Everett interpreted this equation as a mesaure of the account that has system (1) in the state $|si\rangle$, system (2) in the state $|sj\rangle$, and so on

The correspondence between worlds and accounts is not one-to-one, but many-to-one

4. QUANTUM MECHANICS IS COMPLETE

"Many Worlds Interpretation"

The correspondence between worlds and accounts is not one-to-one, but many-to-one

- The sequence of events has a measure :

$$|c_i|^2 \cdot |c_j|^2 \cdot |c_k|^2, \ldots$$

- If we randomly choose a world, the probability of this sequence equals its measure and the probability that a measurement on system *1* yelds |si⟩ is |ci|^2, system *2* yelds |sj⟩ is |cj|^2, and so on

5. CONCLUSION

- A large number of theories were developed in an attempt to prove or disprove the completeness of Quantum Mechanics, involving other postulates like the collapse of the wavefuncition
- Many questions can be discussed: How can we define collapse? ? Do systems have pre existing states and do we just measure them to reveal it or our observations do produce the state? How can we "access"other worlds and demonstrate concretely that multiple exclusive accounts are all real?
- Despite the fact that the experimental thought was considered an absurd even by its creator, today we have "Schrödinger cat states": entangled states that can be generated even for macroscopic systems

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THANKS!