The Many-Worlds Interpretation

Lev Vaidman

Foundations and Interpretation of Quantum Theory (Winter 2010)
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04/05/2005

Foundations and Interpretation of Quantum Theory (Winter 2005)
Welcome To The Quantum World Splitter

You now have a control over a Quantum Optics Laboratory in Tel Aviv University.
When you push SPLIT you will preform a quantum experiment with single photons.
You can choose from splitting 2 up to 6 worlds, they will be created with a copy of you in each world.

If you want to choose between several options in your life, now you can do them all at once.

Choose how many worlds you want to split by pressing one of the red dice faces.
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Quantum Optics Lab
The Quantum World Splitter

Welcome Split

Please enter your options

Left

Split

More info
Further exploration - This link explains: The Many-Worlds Interpretation (MWI) approach to quantum mechanics.
Quantum Optics Lab
The Quantum World Splitter

More info
- Further information
- This link explains:
The Many-Worlds Interpretation (MWI)
approach to quantum mechanics.

You are in Center World
Click here to for additional splitting
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You now have a control over a Quantum Optics Laboratory In Tel Aviv University. When you push SPLIT you will preform a quantum experiment with single photons. You can choose from splitting 2 up to 6 worlds, they will be created with a copy of you in each world.

If you want to choose between several options in your life, now you can do them all at once.

Choose how many worlds you want to split by pressing one of the red dice faces.
All is $\Psi$
All is ψ
A superior statement about the objective characteristics of our quantum world, of the things in it, would contain no $|\psi\rangle$'s at all.

Really, none!
Hope: Today’s physics explains all what we see.
Hope: Today’s physics explains all what we see.

Big hope: Today’s physics explains All.
Hope:  Today’s physics explains all what we see.
Big hope:  Today’s physics explains All.
If $\psi$ is not All, what is?
Hope: Today’s physics explains all what we see.

Big hope: Today’s physics explains All.

If $\psi$ is not All, what is?

Bohr (SEP): The quantum mechanical formalism does not provide physicists with a ‘pictorial’ representation: the $\psi$-function does not, as Schrödinger had hoped, represent a new kind of reality. Instead, as Born suggested, the square of the absolute value of the $\psi$-function expresses a probability amplitude for the outcome of a measurement.
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Bohr and today’s majority of physicists gave up the hope I think, we should not.
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Bohr and today’s majority of physicists gave up the hope I think, we should not.

"Of course the main goal of science is to predict and control phenomena... But we also want to understand how Nature works."

-Joseph Emerson, Lecture 1
All is $\Psi$
All
All is a closed system which can be observed
All is a closed system which might include an observer which can be observed.
All

All is a closed system which might include an observer which can be observed
What is $\psi$?

There is no sharp answer. Theoretical physicists are very flexible in adapting their tools, and no axiomization can keep up with them. But it is fair to say that there are two core ideas of quantum field theory.

First: The basic dynamical degrees of freedom are operator functions of space and time - quantum fields.

Second: The interaction of these fields are local in space and time.

F. Wilczek (in Compendium of Quantum Physics, 2009)
All

All is a closed system which might include an observer which can be observed
What is ψ?

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Second: The interaction of these fields are local in space and time.

F. Wilczek (in Compendium of Quantum Physics, 2009)

$$\Psi(A^a_\mu(\vec{r}), \psi^a_\mu(\vec{r}))$$
What is $\psi$?

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First: The basic dynamical degrees of freedom are operator functions of space and time—quantum fields.

Second: The interaction of these fields are local in space and time.

F. Wilczek (in Compendium of Quantum Physics, 2009)

\[
\Psi(A^a_\mu(\vec{r}), \psi^a_\mu(\vec{r})), \quad \Psi(\vec{r})
\]
Space is taken for granted
Space is taken for granted

\[ \Psi(\vec{r}) \]
There is no collapse
There is no collapse

All is $|\Psi\rangle + \text{Collapse} \implies \text{randomness}$
There is no collapse

All is $|\Psi\rangle + \text{Collapse} \Rightarrow \text{randomness}$

$|\Psi\rangle = \frac{1}{\sqrt{2}} (|a\rangle + |b\rangle)$
There is no collapse

All is $|\Psi\rangle + \text{Collapse}$ $\Rightarrow$ randomness

$|\Psi\rangle = \frac{1}{\sqrt{2}}(|a\rangle + |b\rangle)$

Measurement in $A$: $P_A = ?$
There is no collapse

All is $|\Psi\rangle + \text{Collapse} \Rightarrow \text{randomness}$

$|\Psi\rangle = \frac{1}{\sqrt{2}} (|a\rangle + |b\rangle)$

**MEASUREMENT IN A:** $P_A = ?$

$P_A = 1$

**OR**

random event

by definition $P_\bot = 0$
There is no collapse

All is $|\Psi\rangle + \text{Collapse} \quad \Rightarrow \quad \text{randomness action at a distance}$

$\left| \Psi \right\rangle = \frac{1}{\sqrt{2}} (|a\rangle + |b\rangle)$
There is no collapse

All is $|\Psi\rangle + \text{Collapse} \implies$ randomness action at a distance

$|\Psi\rangle = \frac{1}{\sqrt{2}} (|a\rangle + |b\rangle) = \frac{1}{\sqrt{2}} (|1\rangle_A |0\rangle_B + |0\rangle_A |1\rangle_B)$
There is no collapse

All is $|\Psi\rangle + \text{Collapse}$  \quad \Rightarrow \quad \text{randomness action at a distance}

$$|\Psi\rangle = \frac{1}{\sqrt{2}} (|a\rangle + |b\rangle) = \frac{1}{\sqrt{2}} (|1\rangle_A |0\rangle_B + |0\rangle_A |1\rangle_B)$$

$$\rho_A = \begin{pmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{pmatrix} \qquad \rho_B = \begin{pmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{pmatrix}$$
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MEASUREMENT IN A: $P_A = ?$
There is no collapse

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MEASUREMENT IN $A$ : $P_A = ?$

$P_A = 1$

$\rho_B = \begin{pmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{pmatrix} \rightarrow \begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix}$
There is no collapse

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NO MEASUREMENT IN A: $P_A = ?$
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**MEASUREMENT IN A**: $P_A = ?$

no collapse

$\frac{1}{\sqrt{2}} |R\rangle_{MD} (|1\rangle_A |0\rangle_B + |0\rangle_A |1\rangle_B)$

$\rightarrow \frac{1}{\sqrt{2}} (|1\rangle_{MD} |1\rangle_A |0\rangle_B + |0\rangle_{MD} |0\rangle_A |1\rangle_B)$

$\rho_B = \begin{pmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{pmatrix}$
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All is $|\Psi\rangle + \text{Collapse} \implies \text{randomness action at a distance}$

$|\Psi\rangle = \frac{1}{\sqrt{2}} (|a\rangle + |b\rangle) = \frac{1}{\sqrt{2}} (|1_A\rangle |0_B\rangle + |0_A\rangle |1_B\rangle)$

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$\rho_B = \begin{pmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{pmatrix}$

MEASUREMENT IN A: $P_A = ?$

no collapse

$\frac{1}{\sqrt{2}} |R_{MD}\rangle (|1_A\rangle |0_B\rangle + |0_A\rangle |1_B\rangle)$

$\rightarrow \frac{1}{\sqrt{2}} (|1_{MD}\rangle |1_A\rangle |0_B\rangle + |0_{MD}\rangle |0_A\rangle |1_B\rangle)$

$\rho_B = \begin{pmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{pmatrix} \rightarrow \begin{pmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{pmatrix}$

NO CHANGE
There is no collapse

Bell: 

All is $|\Psi\rangle$ + Collapse $\Rightarrow$ randomness

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MEASUREMENT IN $A$: $P_A = ?$

$P_A = 1$

OR random event

$P_A = 0$ because $P_A$ was not definite before
Measurements do not have (single) outcomes

Bell:

Measurements have single outcomes \( \Rightarrow \) randomness

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**Bell:** Measurements have single outcomes \[ \Rightarrow \] randomness action at a distance

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**NO MEASUREMENT IN A:** \[ P_A = ? \]
There is no collapse

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\[ \rho_B = \begin{pmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{pmatrix} \]

NO MEASUREMENT IN A: \[ P_A = ? \]

\[ \rho_B = \begin{pmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{pmatrix} \]

because \[ P_B \] was not definite before
Measurements do not have (single) outcomes

**Bell:**

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|\Psi\rangle = \frac{1}{\sqrt{2}} (|a\rangle + |b\rangle) = \frac{1}{\sqrt{2}} (|1\rangle_A |0\rangle_B + |0\rangle_A |1\rangle_B)
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\]

**MEASUREMENT IN A:** \( P_A = ? \)

\[
P_A = 1
\]

\[
\rho_B = \begin{pmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{pmatrix} \rightarrow \begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix}
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Measurements do not have (single) outcomes

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\]

\[
\rho_A = \begin{pmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{pmatrix}
\quad \rho_B = \begin{pmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{pmatrix}
\]

Measurement in \( A \): \( P_A = ? \)

\[
P_A = 0
\]

\[
\rho_B = \begin{pmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{pmatrix} \rightarrow \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}
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Measurements do not have (single) outcomes

Bell: Measurements have single outcomes $\Rightarrow$ randomness action at a distance

$|\Psi\rangle = \frac{1}{\sqrt{2}} (|a\rangle + |b\rangle) = \frac{1}{\sqrt{2}} (|1\rangle_A |0\rangle_B + |0\rangle_A |1\rangle_B)$

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MEASUREMENT IN A: $P_A = \ ?$

$P_A = 1$

OR

random event

$P_A = 0$

because $P_A$ was not definite before

OR

$\rho_B = \begin{pmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{pmatrix} \rightarrow \begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix}$
Measurements do not have (single) outcomes

**Bell:**

Measurements have single outcomes $\implies$ randomness action at a distance

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**MEASUREMENT IN A:** $P_A = ?$

$P_A = 1$

**OR**

random event

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because $P_A$ was not definite before

**PROPER MIXTURE?**

$$\rho_B = \begin{pmatrix} \frac{1}{2} & 0 \\ 0 & \frac{1}{2} \end{pmatrix} \rightarrow \begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix}$$

**OR**

$$\rho_B = \begin{pmatrix} 1 & 0 \\ 0 & 0 \end{pmatrix}$$
Measurements do not have (single) outcomes

Bell: Measurements have single outcomes $\Rightarrow$ randomness action at a distance

$|\Psi\rangle = \frac{1}{\sqrt{2}}(|a\rangle + |b\rangle) = \frac{1}{\sqrt{2}}(|1\rangle_A |0\rangle_B + |0\rangle_A |1\rangle_B)$

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MEASUREMENT IN A: $P_A =$ ?

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OR

random event

$P_A = 0$

because $P_A$ was not definite before

PROPER MIXTURE DOES NOT EXIST
All is $\Psi(r,t)$ evolving according to relativistic generalization of the Schrödinger equation

NO COLLAPSE!

All is a single Universe $\Psi(\vec{r}_1, \vec{r}_2, \ldots, \vec{r}_N, t)$
A CENTURY AGO:

All is particles evolving according to Newton’s equations

\[
\left( \vec{r}_1(t), \vec{r}_2(t), \ldots, \vec{r}_N(t) \right)
\]

Laplacian determinism
Laplacian determinism

Experience $\iff \left( \vec{r}_1(t), \vec{r}_2(t), \ldots, \vec{r}_N(t) \right)$

The Many Worlds Interpretation

Experience $\iff \Psi(\vec{r}_1, \vec{r}_2, \ldots, \vec{r}_N, t)$
Laplacian determinism

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The Many Worlds Interpretation

Many Experiences $\iff \Psi(\vec{r}_1, \vec{r}_2, \ldots, \vec{r}_N, t)$
The Many Worlds Interpretation

Many Experiences $\iff \Psi(\vec{r}_1, \vec{r}_2, \ldots, \vec{r}_N, t)$
The Many Worlds Interpretation

Many Experiences $\iff$ \( \Psi(\vec{r}_1, \vec{r}_2, \ldots, \vec{r}_N, t) \)

many experiences $\iff$ many worlds $\iff$ \( \Psi(\vec{r}_1, \vec{r}_2, \ldots, \vec{r}_N, t) \)
The Many Worlds Interpretation

Many Experiences $\iff \Psi(r_1, r_2, \ldots, \hat{r}_N, t)$

many experiences $\iff$ many worlds $\iff \Psi_i(r_1, r_2, \ldots, \hat{r}_N, t)$

experience $i \iff$ world $i$ $\iff \Psi_i(r_1, r_2, \ldots, \hat{r}_N, t)$

$\Psi(r_1, r_2, \ldots, \hat{r}_N, t) = \sum \alpha_i \Psi_i(r_1, r_2, \ldots, \hat{r}_N, t)$
What is “a world” in the many-worlds picture?

experience \_i \quad \Leftrightarrow \quad \text{world} \_i \quad \Leftrightarrow \quad \Psi_i(r_1, r_2, \ldots, r_N, t)
What is “a world” in the many-worlds picture?

experience \_i \iff \text{world } \_i \iff \Psi_i(r_1, r_2, \ldots, r_N, t)

An observer has definite experience.

Everett’s Relative State World
What is "a world" in the many-worlds picture?

experience \( i \) ↔ world \( i \) ↔ \( \Psi_i(\vec{r}_1, \vec{r}_2, \ldots, \vec{r}_N, t) \)

An observer has definite experience.

Everett's Relative State World

\[
\Psi_i = \psi_i^{\text{OBSERVER}} \phi_i^{\text{REST}}
\]
What is “a world” in the many-worlds picture?

experience \_i \iff \text{world} \_i \iff \Psi_i(\vec{r}_1, \vec{r}_2, \ldots, \vec{r}_N, t)

An observer has definite experience.

Everett’s Relative State World

A world is the totality of (macroscopic) objects: stars, cities, people, grains of sand, etc. in a definite classically described state.

The MWI in SEP
What is “a world” in the many-worlds picture?

experience $i \iff$ world $i \iff \Psi_i(r_1, r_2, \ldots, r_N, t)$

An observer has definite experience.

Everett’s Relative State World

A world is the totality of (macroscopic) objects: stars, cities, people, grains of sand, etc. in a definite classically described state.

The MWI in SEP

$$\Psi_i = \psi_i^{\text{OBSERVER}} \phi_i^{\text{REST}}$$

$$\Psi_i = \psi_i^{\text{OBJECT}_1} \psi_i^{\text{OBJECT}_2} \ldots \psi_i^{\text{OBJECT}_K} \phi_i^{\text{REST}}$$

$\Psi_i^{\text{OBJECT}}$ is a Localized Wave Packet for a period of time.
A tale of a single world universe

The king forbade spinning on distaff or spindle, or the possession of one, upon pain of death, throughout the kingdom.
A tale of a single world universe

The king forbade performing quantum measurements, or the possession of quantum devices, upon pain of death, throughout the kingdom.
A tale of a single world universe

\[ \Psi_{\text{UNIVERSE}} = \Psi_{\text{WORLD}} = \psi_{\text{OBJECT}_1} \psi_{\text{OBJECT}_2} \ldots \psi_{\text{OBJECT}_K} \phi^{\text{REST}} \]
A tale of a single world universe

\[ \Psi_{\text{UNIVERSE}} = \Psi_{\text{WORLD}} = \psi_{\text{OBJECT}_1} \psi_{\text{OBJECT}_2} \ldots \psi_{\text{OBJECT}_K} \varphi_{\text{REST}} \]

Quantum states of all macroscopic objects are Localized Wave Packets all the time.
A tale of a single world universe

\[ \psi_{\text{UNIVERSE}} = \psi_{\text{WORLD}} = \psi_{\text{OBJECT}_1} \psi_{\text{OBJECT}_2} \ldots \psi_{\text{OBJECT}_K} \phi \]

Quantum states of all macroscopic objects are Localized Wave Packets all the time.

Zero approximation: all particles remain in product LWP states \( \psi^n(\vec{r}_n) \)

\[ \psi_{\text{WORLD}}(\vec{r}_1, \vec{r}_2, \ldots, \vec{r}_N, t) = \psi^1(\vec{r}_1) \psi^2(\vec{r}_2) \ldots \psi^M(\vec{r}_N) \]
A tale of a single world universe

\[ \psi_{\text{UNIVERSE}} = \psi_{\text{WORLD}} = \psi_{\text{OBJECT}_1} \psi_{\text{OBJECT}_2} \ldots \psi_{\text{OBJECT}_K} \psi_{\text{REST}} \]

Quantum states of all macroscopic objects are Localized Wave Packets all the time.

Zero approximation: all particles remain in product LWP states \( \psi^n (\vec{r}_n) \)

\[ \psi_{\text{WORLD}} (\vec{r}_1, \vec{r}_2, \ldots, \vec{r}_N, t) = \psi^1 (\vec{r}_1) \psi^2 (\vec{r}_2) \ldots \psi^N (\vec{r}_N) \]

Particles which do not interact strongly with “macroscopic objects” need not be in LWP states.

\[ \psi_{\text{WORLD}} = \psi^1 (\vec{r}_1) \psi^2 (\vec{r}_2) \ldots \psi^K (\vec{r}_K) \psi_{\text{REST}} \]
A tale of a single world universe

\[ \Psi_{\text{UNIVERSE}} = \Psi_{\text{WORLD}} = \psi_{\text{OBJECT}_1} \psi_{\text{OBJECT}_2} \ldots \psi_{\text{OBJECT}_K} \phi_{\text{REST}} \]

Quantum states of all macroscopic objects are Localized Wave Packets all the time.

Zero approximation: all particles remain in product LWP states

\[ \Psi_{\text{WORLD}} (\vec{r}_1, \vec{r}_2, \ldots, \vec{r}_N, t) = \psi^1 (\vec{r}_1) \psi^2 (\vec{r}_2) \ldots \psi^N (\vec{r}_N) \]

Particles which do not interact strongly with “macroscopic objects” need not be in LWP states.

\[ \Psi_{\text{WORLD}} = \psi^1 (\vec{r}_1) \psi^2 (\vec{r}_2) \ldots \psi^K (\vec{r}_K) \phi_{\text{REST}} \]

Particles which make atoms, molecules, etc. can (and should be) entangled among themselves. Only states of the center of mass of molecules, cat’s nails etc. have to be in LWP states.
A tale of a single world universe

Quantum states of all macroscopic objects are localized Wave Packets all the time

\[ \Psi_{\text{UNIVERSE}}(\vec{r}_1, \vec{r}_2, \ldots, \vec{r}_N, t) = \psi^1(\vec{r}_1) \psi^2(\vec{r}_2) \ldots \psi^N(\vec{r}_N) \]

\[ \Psi_{\text{WORLD}} = \psi^i(\vec{r}^\text{CM}_i) \phi^i_{\text{rel}}(\vec{r}^i - \vec{r}^j) \psi^j(\vec{r}^\text{CM}_j) \phi^j_{\text{rel}}(\vec{r}^j - \vec{r}^\text{CM}_i) \ldots \psi^M(\vec{r}^\text{CM}_M) \phi^M_{\text{rel}}(\vec{r}^\text{CM}_M - \vec{r}^\text{CM}_i) \Phi^{\text{REST}} \]
A tale of a single world universe

Quantum states of all macroscopic objects are localized Wave Packets all the time

\[
\Psi_{\text{UNIVERSE}}(\vec{r}_1, \vec{r}_2, \ldots, \vec{r}_N, t) = \psi^1(\vec{r}_1) \psi^2(\vec{r}_2) \ldots \psi^N(\vec{r}_N)
\]

\[
\Psi_{\text{WORLD}} = \psi_{CM}^1(\vec{r}_{CM1}) \phi_{rel}(\vec{r}_{1i}, \vec{r}_{1j}) \psi_{CM}^2(\vec{r}_{CM2}) \phi_{rel}(\vec{r}_{2i}, \vec{r}_{2j}) \ldots \psi_{CM}^M(\vec{r}_{CMM}) \phi_{rel}(\vec{r}_{Mi}, \vec{r}_{Mj}) \Phi_{\text{REST}}
\]

\[\Rightarrow \rho(\vec{r}) \neq \rho(\vec{r}) \text{ of a cat!}\]
A tale of a single world universe

Quantum states of all macroscopic objects are Localized Wave Packets all the time

\[ \Psi_{UNIVERSE}(\vec{r}_1, \vec{r}_2, \ldots, \vec{r}_N, t) = \psi^1(\vec{r}_1) \psi^2(\vec{r}_2) \ldots \psi^N(\vec{r}_N) \]

\[ \Phi^{WORLD} = \psi_{CM}^i(\vec{r}_{CM}^i) \phi_{rel}(\vec{r}_{1i} - \vec{r}_{1j}) \psi_{CM}^2(\vec{r}_{CM}^2) \phi_{rel}(\vec{r}_{2i} - \vec{r}_{2j}) \ldots \psi_{CM}^M(\vec{r}_{CM}^M) \phi_{rel}(\vec{r}_{Mi} - \vec{r}_{Mj}) \Phi^{REST} \]

\[ \Rightarrow \quad \rho(\vec{r}) \]

\[ \rho(\vec{r}) \text{ of a cat!} \]
A tale of a single world universe

Quantum states of all macroscopic objects are Localized Wave Packets all the time

\[
\Psi_{\text{UNIVERSE}}(\vec{r}_1, \vec{r}_2, \ldots, \vec{r}_N, t) = \psi^1(\vec{r}_1) \psi^2(\vec{r}_2) \ldots \psi^N(\vec{r}_N) \\
\Psi_{\text{WORLD}} = \psi^i_{\text{CM}}(\vec{r}^{\text{CM}}_1) \phi_{\text{rel}}(\vec{r}_{1i} - \vec{r}_{1j}) \psi^j_{\text{CM}}(\vec{r}^{\text{CM}}_2) \phi_{\text{rel}}(\vec{r}_{2i} - \vec{r}_{2j}) \ldots \psi^M_{\text{CM}}(\vec{r}^{\text{CM}}_M) \phi_{\text{rel}}(\vec{r}_{Mi} - \vec{r}_{Mj}) \Phi_{\text{REST}}
\]

\[\Rightarrow \rho(\vec{r}) \quad \rho(\vec{r}) \text{ of a cat!} \]
A tale of a single world universe

Quantum states of all macroscopic objects are localized Wave Packets all the time

$$\Psi_{UNIVERSE} (\vec{r}_1, \vec{r}_2, ..., \vec{r}_N, t) = \Psi^1 (\vec{r}_1) \Psi^2 (\vec{r}_2) ... \Psi^N (\vec{r}_N)$$

$$\Psi_{WORLD} = \psi_{CM}^1 (\vec{r}_1 \text{ CM}) \phi_{rel}^1 (\vec{r}_1_i - \vec{r}_1_j) \psi_{CM}^2 (\vec{r}_2 \text{ CM}) \phi_{rel}^2 (\vec{r}_2_i - \vec{r}_2_j) ... \psi_{CM}^N (\vec{r}_N \text{ CM}) \phi_{rel}^N (\vec{r}_N_i - \vec{r}_N_j) \Phi_{REST}$$

$$\Rightarrow \rho(\vec{r}) \quad \rho(\vec{r}) \text{ of a cat!}$$

experience \(\Leftrightarrow\) $$\Psi^1 (\vec{r}_1) \Psi^2 (\vec{r}_2) ... \Psi^N (\vec{r}_N)$$
A tale of a single world universe

Quantum states of all macroscopic objects are localized Wave Packets all the time

$$\Psi_{\text{UNIVERSE}}(\vec{r}_1, \vec{r}_2, \ldots, \vec{r}_N, t) = \psi_1(\vec{r}_1) \psi_2(\vec{r}_2) \ldots \psi_N(\vec{r}_N)$$

$$\Psi_{\text{WORLD}} = \psi_{CM_1}(\vec{r}_{CM_1}) \varphi_{\text{rel}}(\vec{r}_{1i} - \vec{r}_{1j}) \psi_{CM_2}(\vec{r}_{CM_2}) \varphi_{\text{rel}}(\vec{r}_{2i} - \vec{r}_{2j}) \ldots \psi_{CM_N}(\vec{r}_{CM_N}) \varphi_{\text{rel}}(\vec{r}_{Mi} - \vec{r}_{Mj}) \Phi$$

$$\Rightarrow \rho(\vec{r})$$

$$\rho(\vec{r})$$ of a cat!

experience

$$\Leftrightarrow$$

$$\psi_1(\vec{r}_1) \psi_2(\vec{r}_2) \ldots \psi_N(\vec{r}_N)$$

Almost the same as in Textbook collapse
A tale of a single world universe

Quantum states of all macroscopic objects are localized Wave Packets all the time:

$$\Psi_{\text{UNIVERSE}}(\vec{r}_1, \vec{r}_2, \ldots, \vec{r}_N, t) = \psi^1(\vec{r}_1) \psi^2(\vec{r}_2) \ldots \psi^N(\vec{r}_N)$$

$$\Psi_{\text{WORLD}} = \psi^1_{\text{CM}}(\vec{r}_1) \phi_{\text{rel}}^1(\vec{r}_{1i} - \vec{r}_{1j}) \psi^2_{\text{CM}}(\vec{r}_2) \phi_{\text{rel}}^2(\vec{r}_{2i} - \vec{r}_{2j}) \ldots \psi^M_{\text{CM}}(\vec{r}_M) \phi_{\text{rel}}^M(\vec{r}_{Mi} - \vec{r}_{Mj}) \Phi$$

$$\Rightarrow \rho(\vec{r})$$

$\rho(\vec{r})$ of a cat!

Experience:

$$\Psi^1(\vec{r}_1) \Psi^2(\vec{r}_2) \ldots \Psi^N(\vec{r}_N)$$

Almost the same as in

Textbook collapse

GRW-Pearle Collapse (mass density)
A tale of a single world universe

Quantum states of all macroscopic objects are localized Wave Packets all the time

$$\Psi_{\text{UNIVERSE}}(\vec{r}_1, \vec{r}_2, \ldots, \vec{r}_N, t) = \psi^1(\vec{r}_1) \psi^2(\vec{r}_2) \ldots \psi^N(\vec{r}_N)$$

$$\Psi_{\text{WORLD}} = \psi^1_{CM}(r^1_{CM}) \phi^1_{rel}(r^i_{1i} - r^i_{1j}) \psi^2_{CM}(r^2_{CM}) \phi^2_{rel}(r^2_{2i} - r^2_{2j}) \ldots \psi^M_{CM}(r^M_{CM}) \phi^M_{rel}(r^M_{Mi} - r^M_{Mj}) \Phi_{\text{REST}}$$

$$\Rightarrow \rho(\vec{r})$$

$\rho(\vec{r})$ of a cat!

experience $\leftrightarrow$ TRIVIAL

$$\psi^1(\vec{r}_1) \psi^2(\vec{r}_2) \ldots \psi^N(\vec{r}_N)$$

Almost the same as in

Textbook collapse

GRW-Pearle Collapse (mass density)

Bohmian trajectories
A tale of a single world universe

Quantum states of all macroscopic objects are localized Wave Packets all the time.

\[
\psi_{\text{UNIVERSE}}(\vec{r}_1, \vec{r}_2, \ldots, \vec{r}_N, t) = \psi^1(\vec{r}_1) \psi^2(\vec{r}_2) \ldots \psi^N(\vec{r}_N)
\]

\[
\psi_{\text{WORLD}} = \psi_{\text{CM}}^1(\vec{r}_1) \phi_{\text{rel}}^1(\vec{r}_{1i} - \vec{r}_{1j}) \psi_{\text{CM}}^2(\vec{r}_2) \phi_{\text{rel}}^2(\vec{r}_{2i} - \vec{r}_{2j}) \ldots \psi_{\text{CM}}^M(\vec{r}_M) \phi_{\text{rel}}^M(\vec{r}_{Mi} - \vec{r}_{Mj}) \Phi_{\text{REST}}
\]

\[\Rightarrow \rho(\vec{r})\]

\[\rho(\vec{r})\] of a cat!

Almost the same as in

Textbook collapse

GRW-Pearle Collapse (mass density)

Bohmian trajectories

Laplacian Determinism
A tale of a single world universe

Quantum states of all macroscopic objects are localized Wave Packets all the time

$$\Psi_{\text{UNIVERSE}} (\vec{r}_1, \vec{r}_2, \ldots, \vec{r}_N, t) = \Psi^1 (\vec{r}_1) \Psi^2 (\vec{r}_2) \ldots \Psi^N (\vec{r}_N)$$

$$\Psi_{\text{WORLD}} = \Psi_{\text{CM}} (\vec{r}^{\text{CM}}_1) \phi_{\text{rel}} (\vec{r}_{1a} - \vec{r}_{1b}) \Psi_{\text{CM}} (\vec{r}^{\text{CM}}_2) \phi_{\text{rel}} (\vec{r}_{2a} - \vec{r}_{2b}) \ldots \Psi_{\text{CM}} (\vec{r}^{\text{CM}}_M) \phi_{\text{rel}} (\vec{r}_{Ma} - \vec{r}_{Mb}) \Phi_{\text{REST}}$$

$$\Rightarrow \rho (\vec{r})$$

\(\rho (\vec{r})\) of a cat!

Experience

$\Leftrightarrow$

$$\Psi^1 (\vec{r}_1) \Psi^2 (\vec{r}_2) \ldots \Psi^N (\vec{r}_N)$$

Almost the same as in

Textbook collapse

GRW-Pearle Collapse (mass density)

Bohmian trajectories

Laplacian Determinism

Compare with "QM as probability theory"