Process Theology as a Lens for Bringing Quantum Physics into Focus

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Lecture 3: From Particles to Equations: Structured Possibility and Primordial Nature

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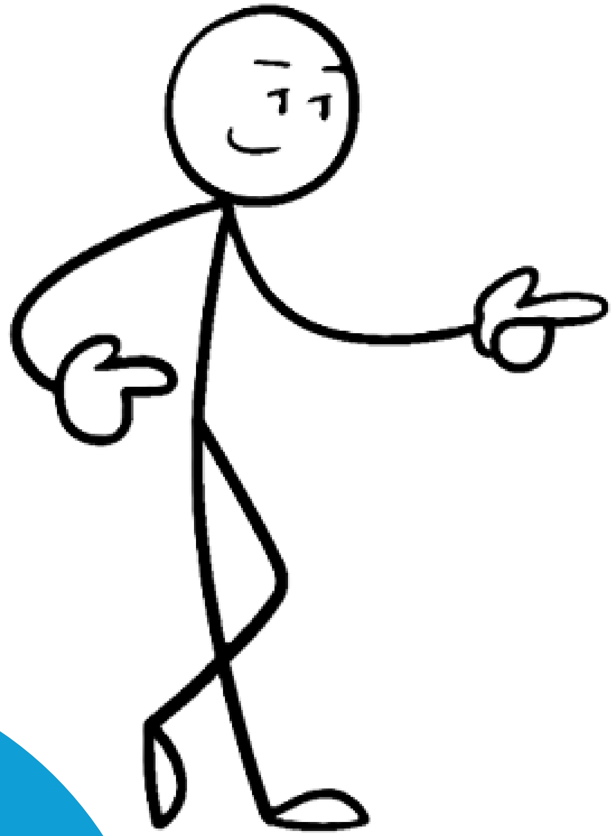
From Particles to Equations: Structured Possibility and Primordial Nature



- **Today's Topic:**

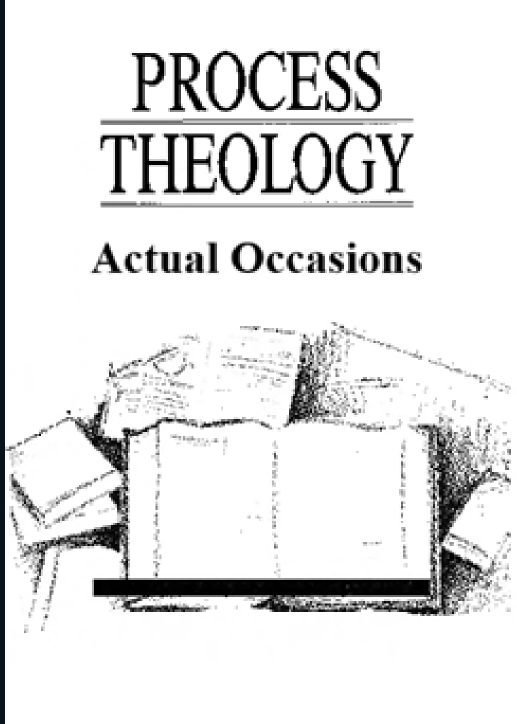
  Quantum States, Hilbert Space, and the Quantum State Machine

- **Today's Lens:**

  Primordial Nature of God as a Process Theology Lens for Quantum States

- **A Critical Move:**
  - **from observed detector events**
    (Lecture 2: Consequent Nature of God: actual occasions)
  - **to quantum states and structured possibility**
    (Lecture 3: Primordial Nature of God)
  - **to the mathematical machinery that organizes and evolves those possibilities**
    (Lecture 4: Construction of the Quantum State Machine)
  - **to the probabilistic emergence of measurable patterns across many actual occasions**
    (Lecture 5: Superjective Nature of God)

Lecture 2 Review Actual Occasions and Detector Events



Lecture 2 Review: Actual Occasions and Particle-Like Detections

Process Theology Language:

- actual occasions
- becoming
- event-centered reality
- relational process

Quantum Physics Gives Us:

- particle-like detection events
- quantized interactions
- measurable properties
- probability distributions

Important Concept

At the quantum level, physics directly observes quantized detector events rather than tiny visible objects.

Consequent Nature and Actual Occasions

Consequent Nature of God

- receives actual occasions
- incorporates realized events
- preserves realized becoming

Quantum Parallel

- detector events become realized outcomes
- measurements produce realized detector events
- experiments study the statistical patterns of becoming emerging across many realized events

Important:

This lecture series uses Process Theology as a conceptual lens, not as a scientific claim.

Building and Running the Quantum State Machine

Lecture 3: Structured Possibility

- **Structured Possibility**
- **quantum states**
- **Hilbert space**
- **vacuum state**
- **probability amplitudes**

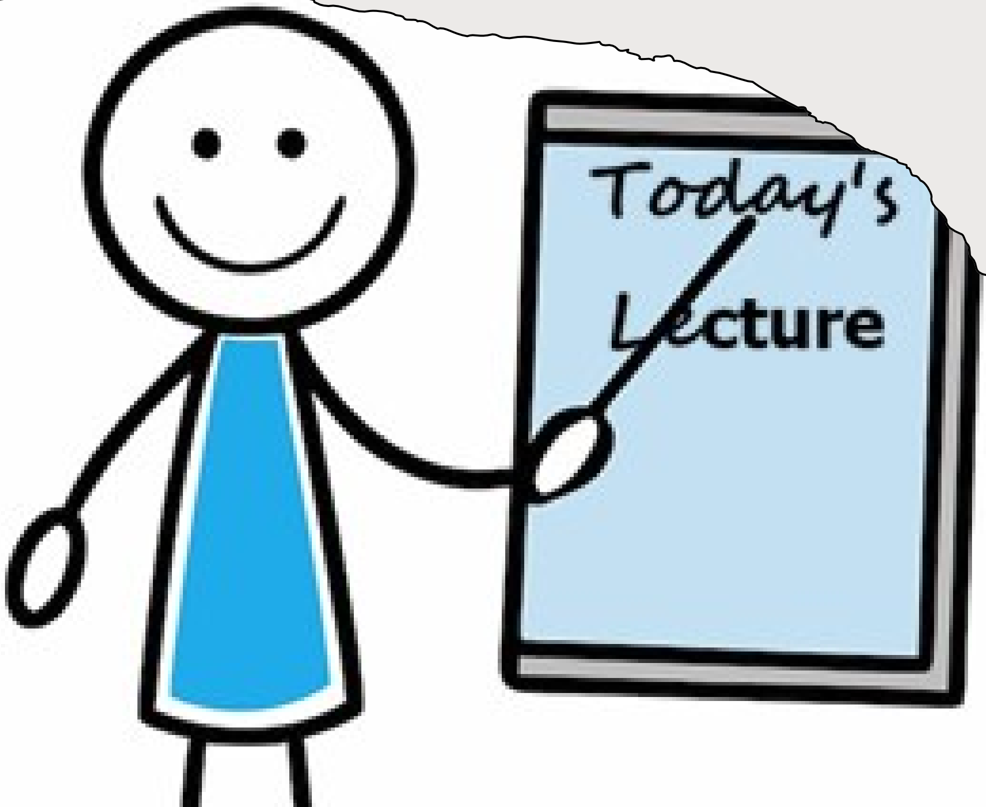
Lecture 4: Construction of the Quantum State Machine

- **Building the Quantum State Machine**
- **fields**
- **operators**
- **quantization**
- **Hamiltonians**

Lecture 5: Probabilistic Becoming

- **Running the Quantum State Machine**
- **time evolution**
- **Born rule**
- **probabilities**
- **emergent patterns**

Primordial Nature and Structured Possibility



Primordial Nature of God

- ordering of possibilities
- relational structure
- constraints on becoming
- potential forms of realization

Quantum Parallel

- quantum states
- Hilbert space
- structured possibility space
- constrained probabilistic emergence

Important:

Quantum states describe structured possibilities for future actual occasions.

What Physics Establishes — and What It Doesn't

When a quantum event is not predetermined, how should we describe it?

A common interpretation is:

- Not predetermined = Random

But that conclusion is not part of the physics.

What Physics Establishes — and What It Doesn't

Physics establishes:

✓ The outcome was not completely predetermined.

Physics does not establish any particular interpretation of that indeterminacy:

✗ Randomness

✗ Agency

✗ Conscious choice

✗ Self-creation

✗ Any other interpretation

Important Point

- Physics establishes the openness.
- Physics does not determine the meaning of the openness.

Free Will in Process Theology

Actual Occasions

In Process Theology, actual occasions:

- inherit conditions from the past
- are influenced by relationships and circumstances
- are constrained but not completely predetermined
- contribute something novel to becoming

Process Theology Language

This openness is often described as:

- free becoming
- freedom within constraints
- self-creativity

Important

- In Process Theology, free will does not mean unlimited freedom.
- It means openness within constraints.

A Free-Will Parallel in Quantum Physics

What Physics Establishes

✓ some quantum events are not completely predetermined by prior information

✓ quantum theory predicts probabilities rather than individual outcomes

✓ statistical patterns emerge across many events

What Physics Does Not Establish

✗ randomness

✗ agency

✗ conscious choice

✗ self-creativity

✗ any other interpretation

Important

- Physics establishes openness but does not determine the meaning of that openness.

Conway–Kochen Free Will

In This Lecture Series

- **We use the term Conway–Kochen Free Will to describe:**
  - **✓ outcomes that are not completely predetermined by prior information**
- **What We Do NOT Mean**

  ✗ consciousness

  ✗ agency

  ✗ deliberate choice

  ✗ human decision making

  ✗ any particular interpretation

Important

- **Randomness and Conway–Kochen free will are instrumentally indistinguishable.**
- **Physics cannot experimentally determine the difference.**

Key Idea

- **Conway–Kochen free will is simply our label for the openness established by physics.**

What Conway and Kochen Provide

John Conway and Simon Kochen developed two Free Will Theorems exploring the implications of free will in quantum physics.

In This Lecture Series

- **We are not using the Free Will Theorems themselves.**
- **We are using the definition of free will employed by Conway and Kochen.**

What Conway and Kochen Provide

In Summary

1. Process Theology has a useful concept called free becoming.
2. Quantum physics finds a similar openness within constraints.
3. Conway and Kochen provide a definition of free will that describes this openness.
4. Quantum states encode the constraints on that openness through probability amplitudes and their mathematical relationships..

Important

- Conway–Kochen free will provides the openness.
- Quantum states encode the constraints on that openness.

Next Question

- How do quantum states encode those constraints?
- With that foundation in place, we now turn to quantum states.

How Do Quantum States Encode Constraints?

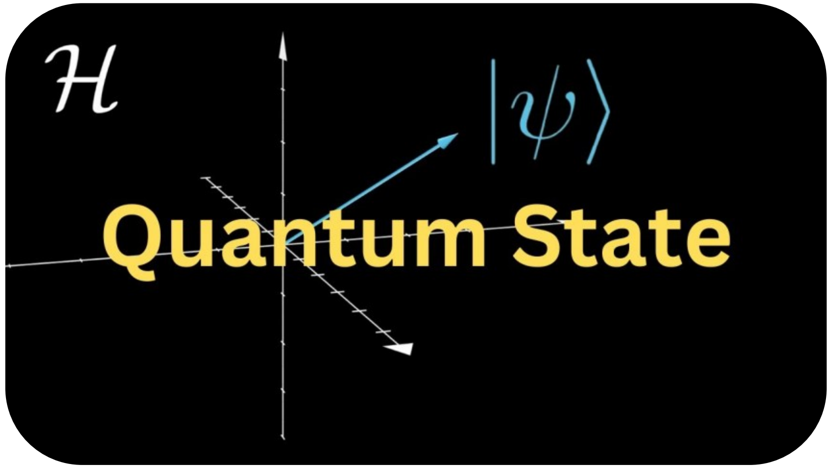
Recall

Quantum states encode the constraints on:

- possible future detections
- measurable properties
- allowed outcomes
- structured possibilities

We begin by examining increasingly complex quantum states:

1. the vacuum state (no particles)
2. one-particle states
3. multi-particle states



Key Idea

Each quantum state encodes:

- which particles are present
- what properties they may exhibit
- which future detections are possible
- the probability amplitudes associated with those possibilities

Important

- Quantum states do not encode certainty.
- They encode structured possibilities.

The Simplest Quantum State: The Vacuum State

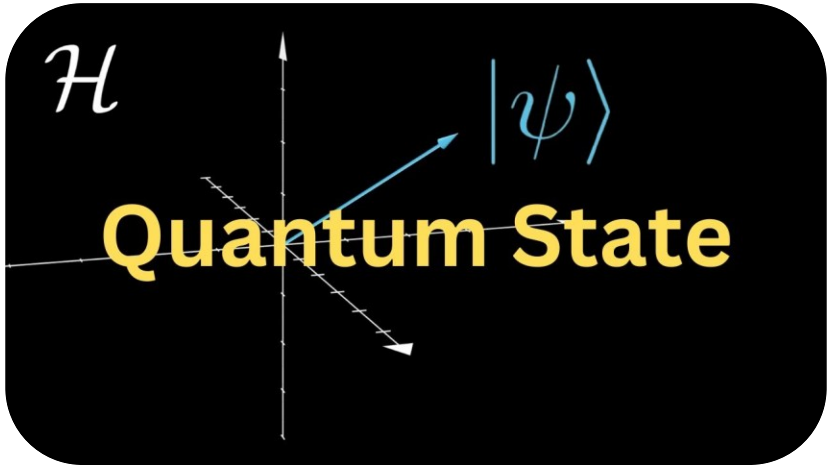
In the Quantum State Model

The vacuum state:

- contains no particles
- represents the lowest-energy state of the model
- is still a valid quantum state
- contains structured possibilities for future particle-like detections

Important

The absence of particles is itself represented by a valid quantum state.



Process Theology Lens

The vacuum state can be viewed as a model of structured possibility prior to actual occasions.

Key Idea

A quantum state does not require particles.

Particles are only one possible content of a quantum state.

Transition

If the vacuum state contains no particles, what happens when we add one?

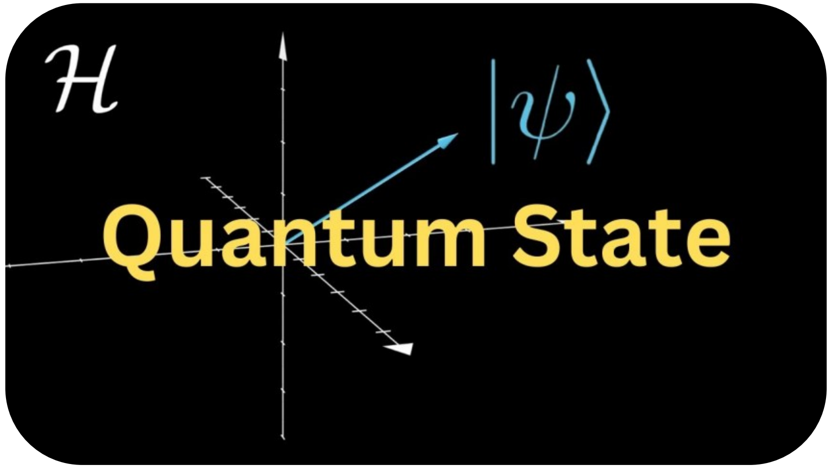
One-Particle Quantum States

Starting from the Vacuum State

- A one-particle quantum state is created when a single particle is added to the model.

Examples

- One Electron State
  - one electron is present
  - electron properties are encoded in the quantum state
  - future particle-like detections are constrained by the quantum state
- One Photon State
  - one photon is present
  - photon properties are encoded in the quantum state
  - future particle-like detections are constrained by that state



Process Theology Lens

- The particle does not remove the openness.
- The quantum state constrains the possible ways that openness can become actual.

Transition

How does the quantum state encode those possibilities and what information needs to be encoded?

What Information Must a Quantum State Encode?

To Predict Future Particle-Like Detections

A quantum state must encode:

- which particles are present
- how many particles are present
- the measurable properties those particles may exhibit
- the possible future particle-like detections
- the relationships among those possibilities

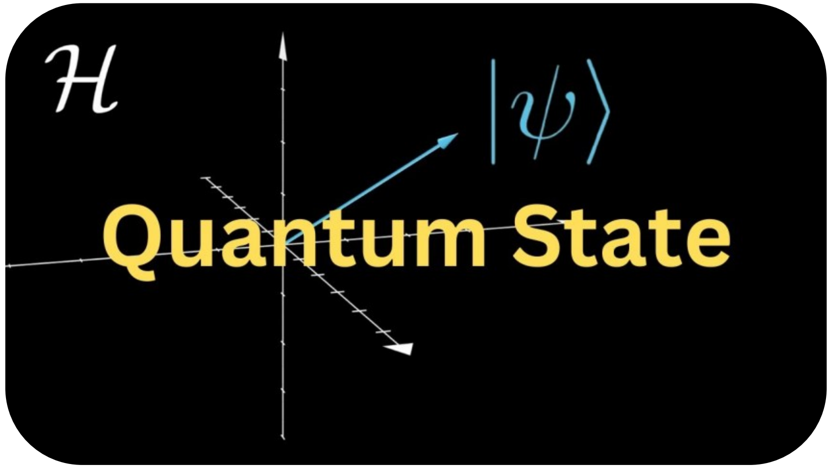
Examples

One Electron State may encode possibilities related to:

- position
- momentum
- energy
- spin

One Photon State may encode possibilities related to:

- position
- momentum
- energy
- spin



Important

- A quantum state does not encode a single predetermined future.
- It encodes a structured set of possible future detections.

Process Theology Lens

- The quantum state encodes the constraints on becoming.
- It does not determine exactly which actual occasion will occur.

Transition

How does the quantum state mathematically encode this information?

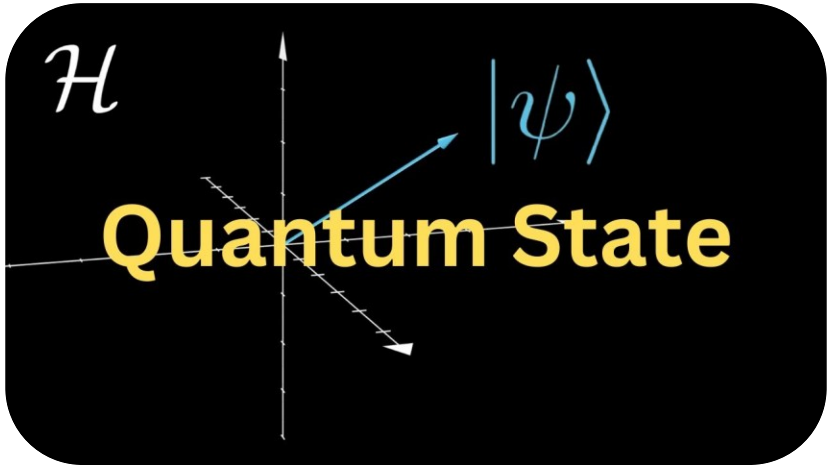
Probability Amplitudes Encode Possibilities

A Quantum State Uses Probability Amplitudes

- A quantum state assigns probability amplitudes to possible future particle-like detections.
- amplitudes are mathematical quantities
- amplitudes can be positive, negative, or complex
- amplitudes are not probabilities
- probabilities are calculated from amplitudes

Example

- For a one-electron state:
  - possible future detections may occur at different locations
  - each possible detection is assigned a probability amplitude
  - the amplitudes determine the probabilities of the possible detections



Important

Probability amplitudes encode the structure of the possibilities.
They do not specify a single predetermined outcome.

Process Theology Lens

Probability amplitudes can be viewed as mathematical constraints on becoming.

Transition

How are all of these amplitudes organized into a single quantum state?

A Simple State Vector

Example: Electron Spin

Suppose an electron can be detected as:

- **Spin Up**
- **Spin Down**

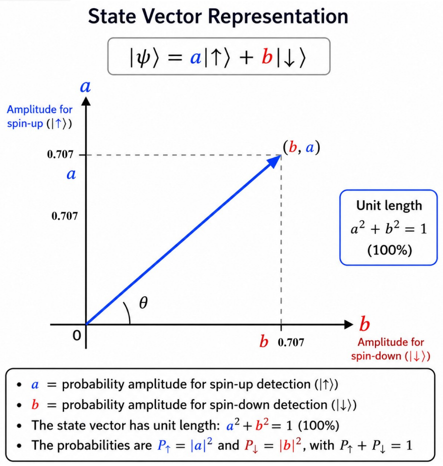
A one-electron quantum state assigns a probability amplitude to each possibility.

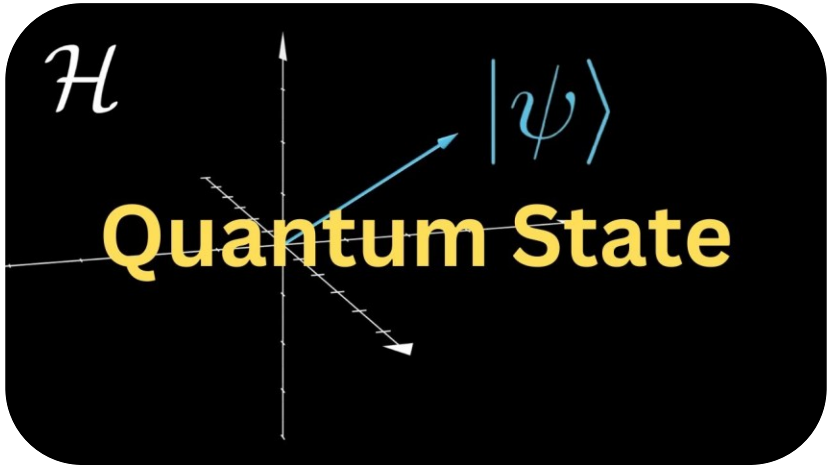
State Vector Representation

$$|\psi\rangle = a\,|\uparrow\rangle + b\,|\downarrow\rangle$$

where:

- **a = probability amplitude for spin-up detection**
- **b = probability amplitude for spin-down detection**





Important

- **This is one quantum state, not two states.**
- **The state contains amplitudes for multiple possible future particle-like detections.**
- **The amplitudes determine the probabilities associated with those detections.**

Process Theology Lens

The quantum state encodes multiple constrained possibilities within a single state.

Transition

How can one quantum state contain amplitudes for multiple possibilities at the same time?

A Simple Sta

Example: El

Suppose an elec
as:

- Spin Up
- Spin Down

A one-electron qua
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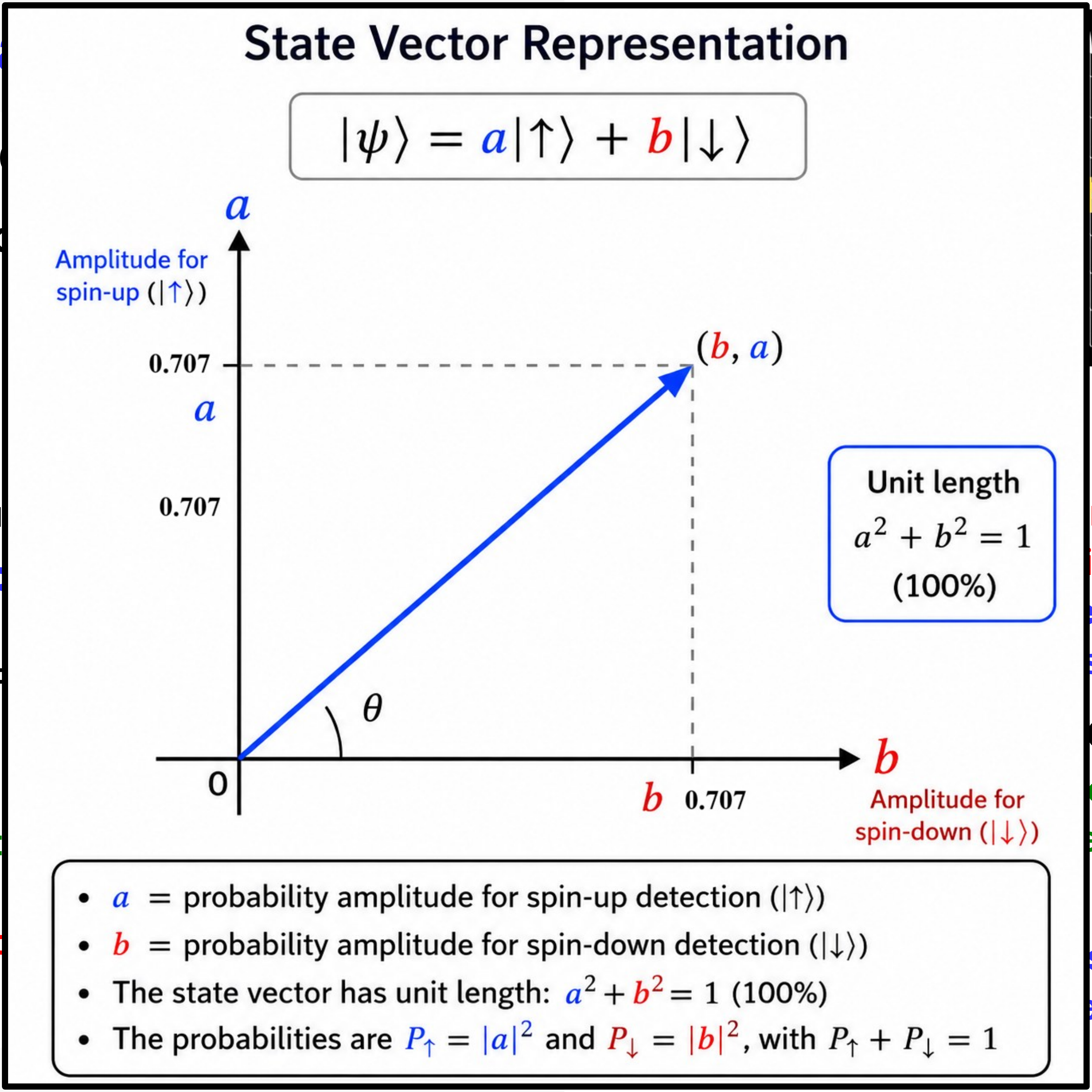
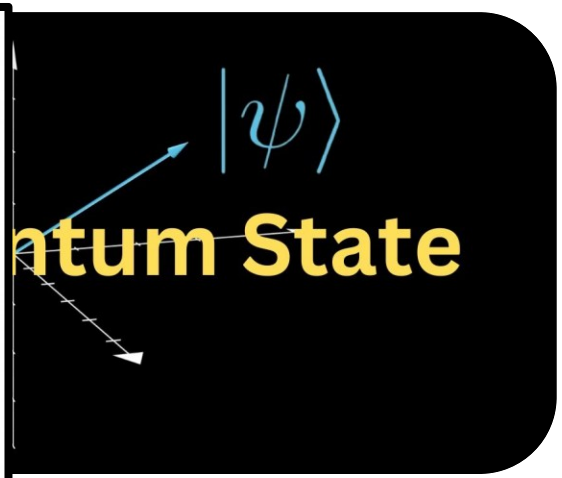
State Vector R

$$|\psi\rangle =$$

where:

- a = probabilit
  detection
- b = probabilit
  detection





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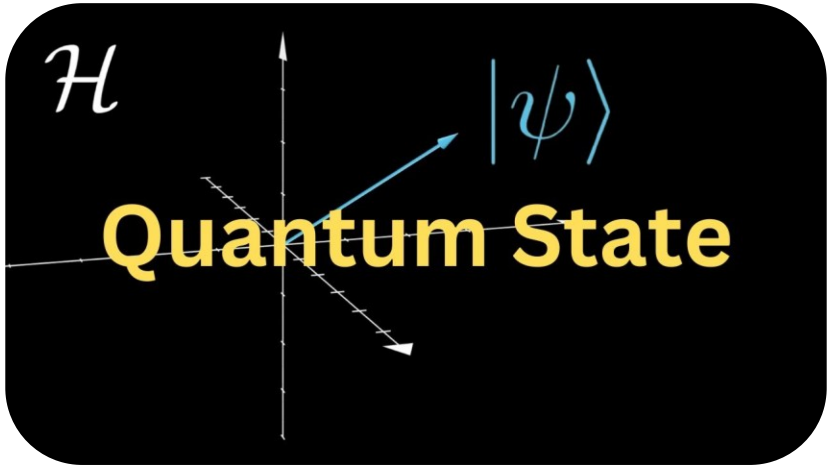
From State Vectors to Hilbert Space

We Have Seen:

- A quantum state can be represented by a state vector.
- The state vector contains probability amplitudes.
- The amplitudes encode possible future particle-like detections.
- Different amplitudes correspond to different probability distributions.

The Next Question:

How are all possible quantum states organized?



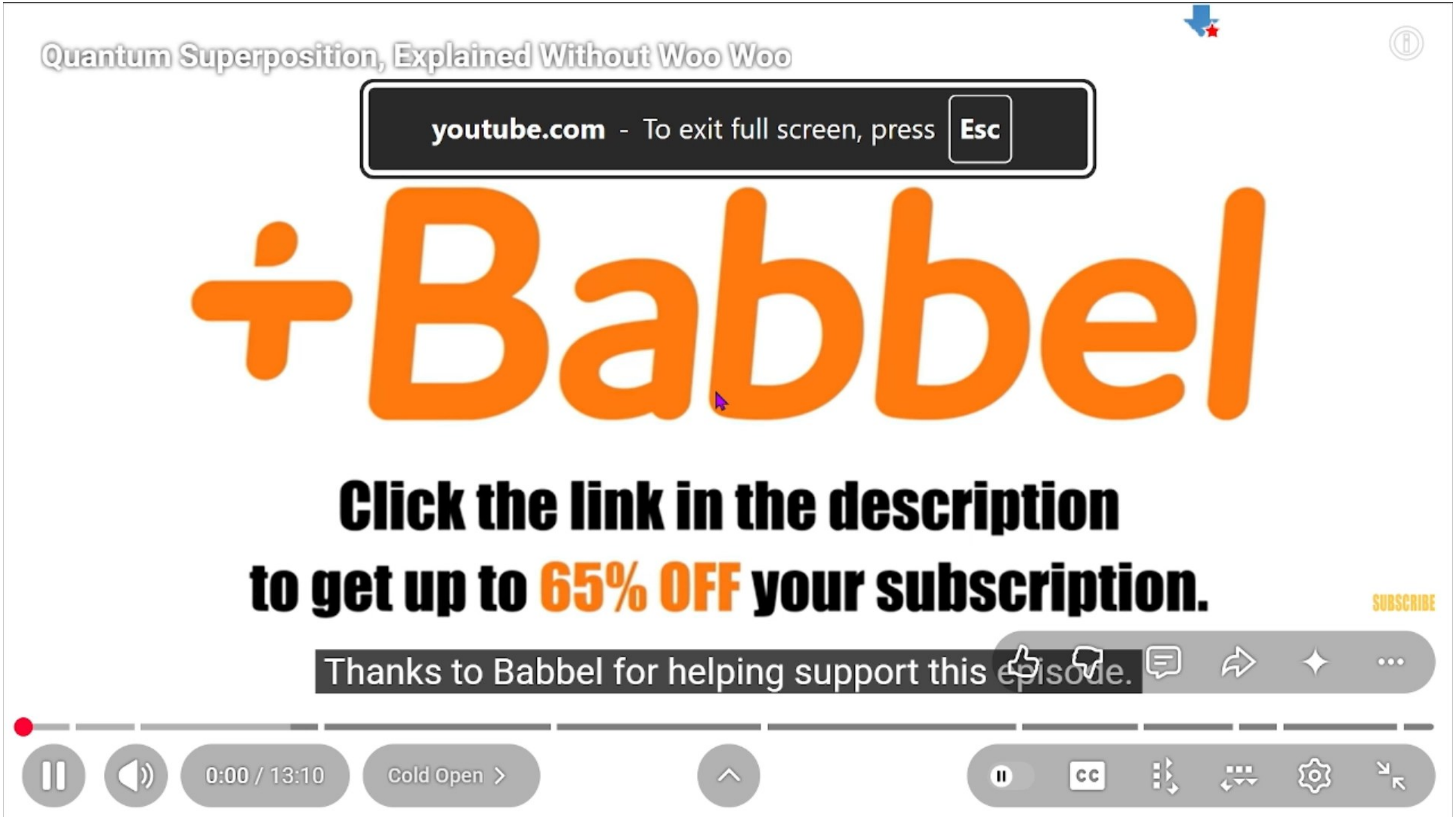
Key Idea

A state vector does not exist by itself.

It exists within a mathematical framework called Hilbert space.

Transition

The following video illustrates how Hilbert space organizes quantum states and why physicists use different bases to describe the same quantum state.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Cold Open

One Quantum State, Many Possible Detections

Key Lesson From The Video

- **A quantum state is represented by a single state vector.**
- **That state can contain probability amplitudes for many possible future particle-like detections.**

Important

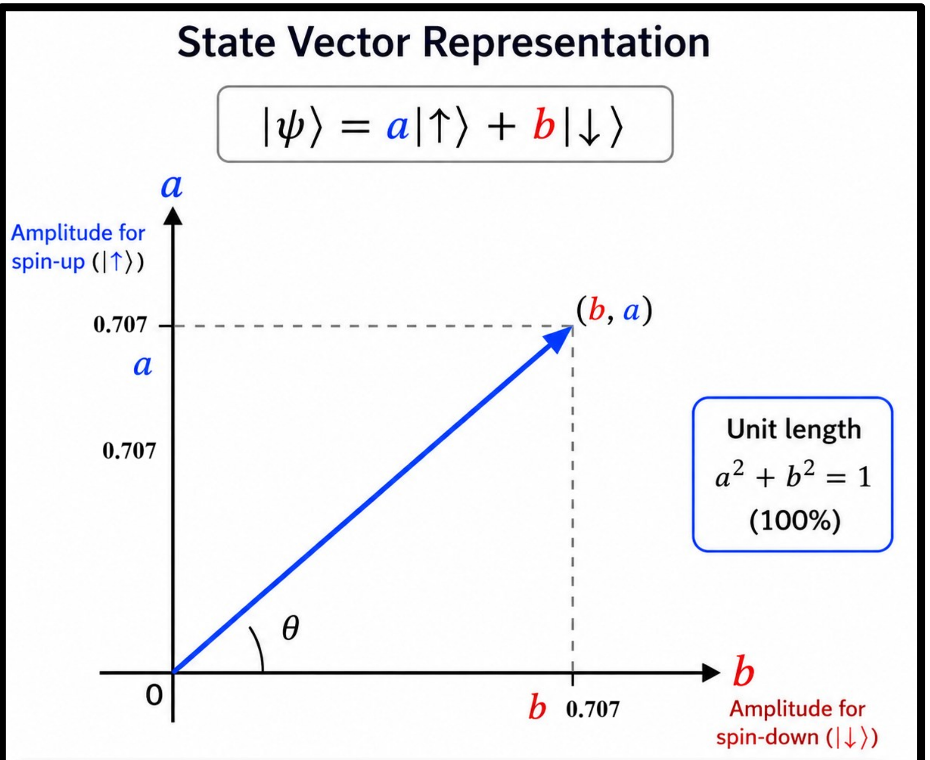
- **One quantum state does not imply one future outcome.**
- **One quantum state can encode many possible future particle-like detections.**

Process Theology Lens

- **One structured possibility can contain many constrained ways of becoming actual.**

Transition

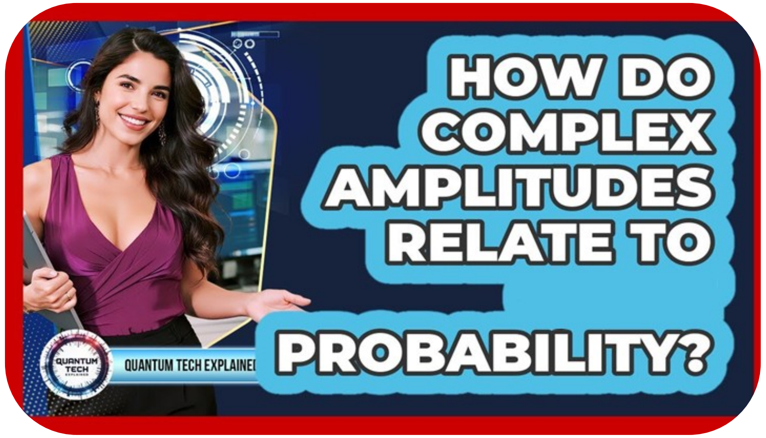
- **How do probability amplitudes become probabilities of future particle-like detections?**



- a = probability amplitude for spin-up detection ($|\uparrow\rangle$)
- b = probability amplitude for spin-down detection ($|\downarrow\rangle$)
- The state vector has unit length: $a^2 + b^2 = 1$ (100%)
- The probabilities are $P_\uparrow = |a|^2$ and $P_\downarrow = |b|^2$, with $P_\uparrow + P_\downarrow = 1$

Notice that this is still only one state vector. The vector has not split into two states. Instead, one state contains probability amplitudes for multiple possible detections

From Probability Amplitudes to Probabilities



The Key Idea

- A quantum state contains probability amplitudes, not probabilities.
- Each possible future particle-like detection is assigned a probability amplitude.
- Probability amplitudes can be positive, negative, or complex-valued.
- The amplitudes themselves are not directly observable.

- The Born Rule

To predict measurable outcomes:

- The probability amplitude is converted into a probability.
- The probability is calculated from the square of the amplitude.
- These probabilities predict the likelihood of future particle-like detections.

Important

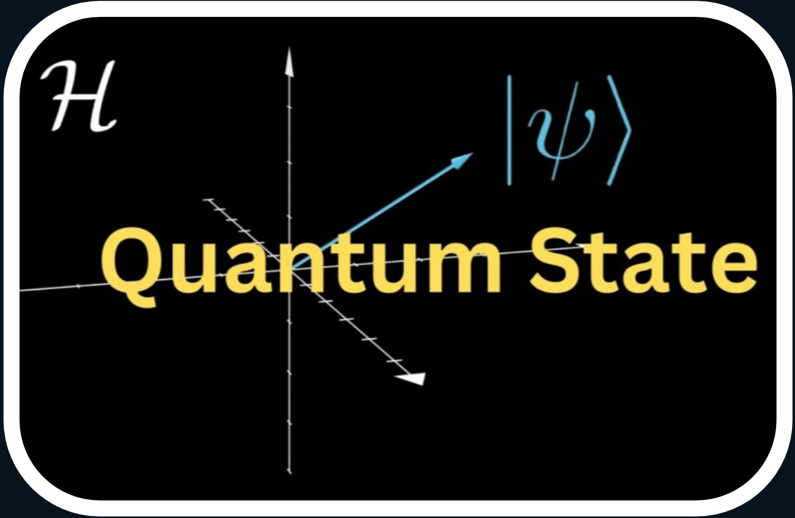
- Physics predicts probabilities of detections, not specific outcomes.
- The quantum state constrains what may occur and how likely each possibility is.

Process Theology Lens

- The amplitudes encode the structure of the possibilities.
- The Born Rule converts that structure into measurable probabilities.

Transition: If a quantum state contains many amplitudes, how are they organized into a single mathematical object?

Hilbert Space Organizes the Possibilities



The Key Idea

A quantum state may contain many probability amplitudes.

Hilbert space provides the mathematical framework that organizes them.

- Each possible future particle-like detection is associated with a probability amplitude.
- Those amplitudes are collected into a single state vector.
- The state vector represents the complete quantum state.
- The state vector exists within Hilbert space.

Important

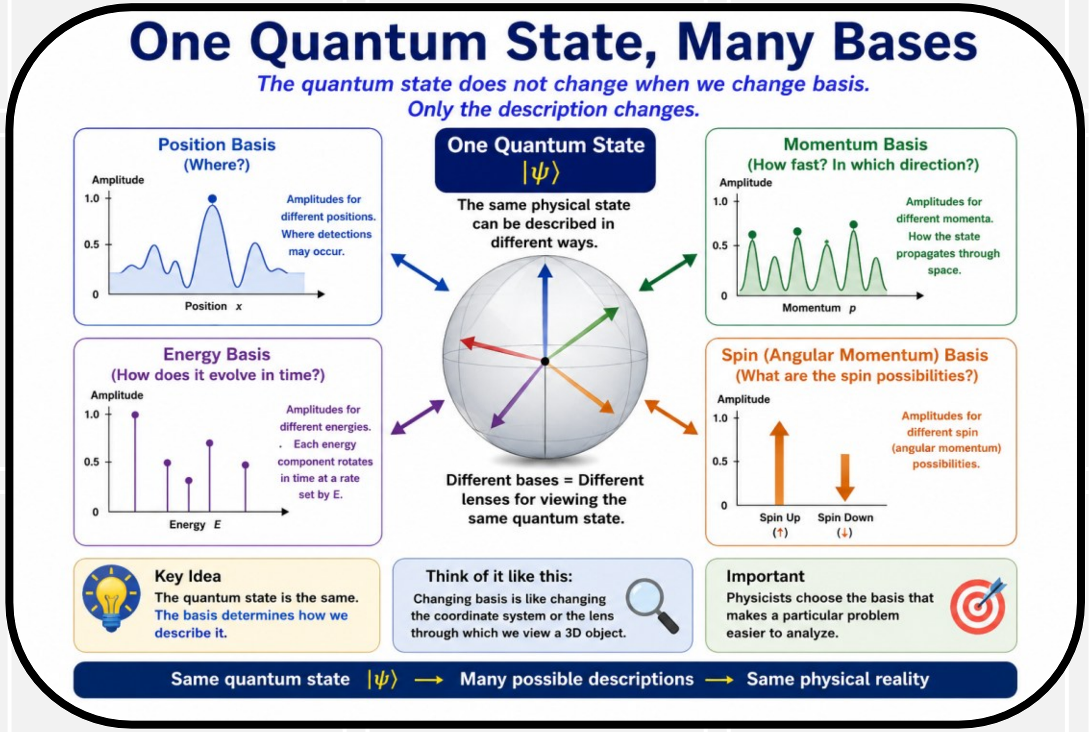
- Hilbert space is part of the mathematical model.
- It provides a way to organize probability amplitudes into a single quantum state.

Process Theology Lens

Hilbert space can be viewed as a mathematical representation of structured possibility.

Transition: If Hilbert space organizes all possibilities, why do physicists use different bases to describe the same quantum state?

One Quantum State Many Bases



The Key Idea

- The quantum state does not change when we change basis.
- Only the description changes.

Examples

The same quantum state can be described in:

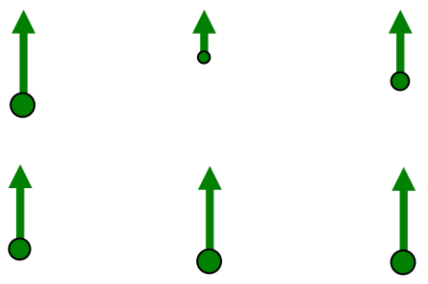
- Momentum basis
- Energy basis
- Angular momentum (spin) basis
- Position basis

Important

- Different bases emphasize different measurable properties.
- Different bases make different aspects of the same quantum state easier to calculate.
- Physicists choose the basis that makes a particular problem easier to calculate.

Transition: Since Hilbert Space is a linear vector space, we can calculate in whichever basis is easiest and then change to Position basis and ADD!

Energy Basis



How Does the Quantum State Evolve in Time?

Example

- A single photon is traveling from a laser toward a detector.

In the Energy Basis

- The quantum state contains probability amplitudes for different possible energies.
- Time evolution is especially simple in this basis.
- Each energy component behaves like a rotating phasor.
- Higher energy components rotate rapidly in time
- Energy determines the rate of rotation.

Important

Energy and time form a natural pair.

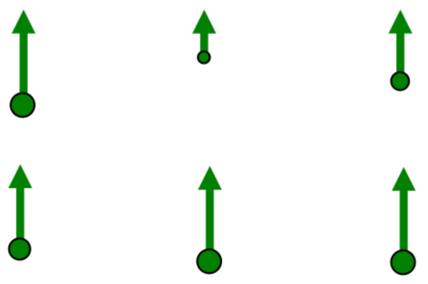
- Energy determines how the quantum state changes with time.
- The energy basis makes time evolution easy to calculate.

Process Theology Lens

The energy basis describes how structured possibilities unfold through time.

Transition: If energy basis makes time evolution simple, what basis makes motion through space simple?

Momentum Basis



How Does the Quantum State Move Through Space?

Example

- A single photon is traveling from a laser toward a detector.

In the Momentum Basis

- The quantum state contains probability amplitudes for different possible momenta.
- Motion through space is especially simple in this basis.
- Each momentum component behaves like a rotating phasor.
- Higher momentum components rotate more rapidly across space.
- Momentum determines the spatial rate of rotation.

Important

Position and momentum form a natural pair.

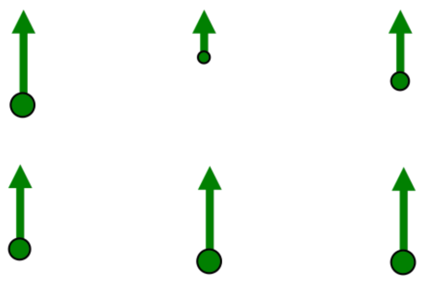
- Momentum determines how the quantum state changes across space.
- The momentum basis makes propagation through space easy to calculate.

Process Theology Lens

The momentum basis describes how possibilities are distributed through space.

Transition: If momentum basis tells us how a quantum state moves through space, what basis tells us about its possible spin detection?

Spin Basis



What Spin Detections Are Possible?

Example

- A single photon is traveling from a laser toward a detector.

In the Spin Basis

- The quantum state contains probability amplitudes for different possible spin detections.
- Spin properties are especially simple in this basis
- Each spin component is assigned a probability amplitude.
- Different spin amplitudes correspond to different possible spin detections.
- Angular momentum determines how the quantum state behaves under rotations.

Important

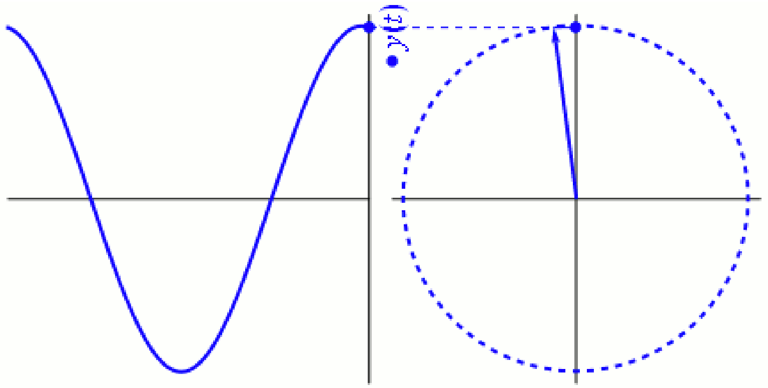
Rotation and angular momentum form a natural pair.

- Angular momentum determines rotational behavior.
- The spin basis makes rotational properties easy to calculate.

Process Theology Lens

The spin basis describes structured possibilities associated with rotational symmetry.

Transition: If energy, momentum, and spin can each be described in their own basis, where do measurable particle-like detections actually occur?



Where Can Particle-Like Detections Occur?

Example

- A single photon is traveling from a laser toward a detector.

In the Position Basis

- Rotations in other bases become waves.
- Particle-like detections are described in terms of position in actual space.
- Contributions from energy, momentum, and spin are combined in this basis.
- Interference between probability amplitudes becomes visible.
- The result is a probability distribution for possible detections.

Important

Position basis is where experiments live.

- Detectors record particle-like detections at specific locations.
- Position basis connects the mathematical model to observable measurements.

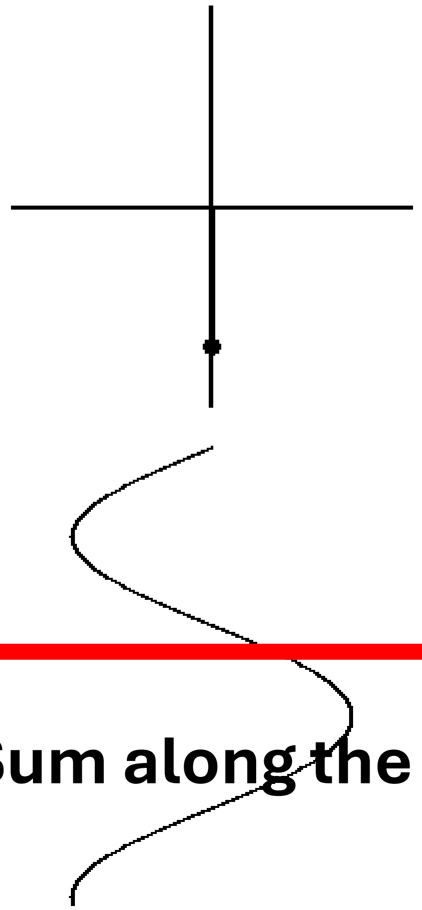
Transition: How can simple rotating phasors in energy and momentum space produce interference patterns in position space?

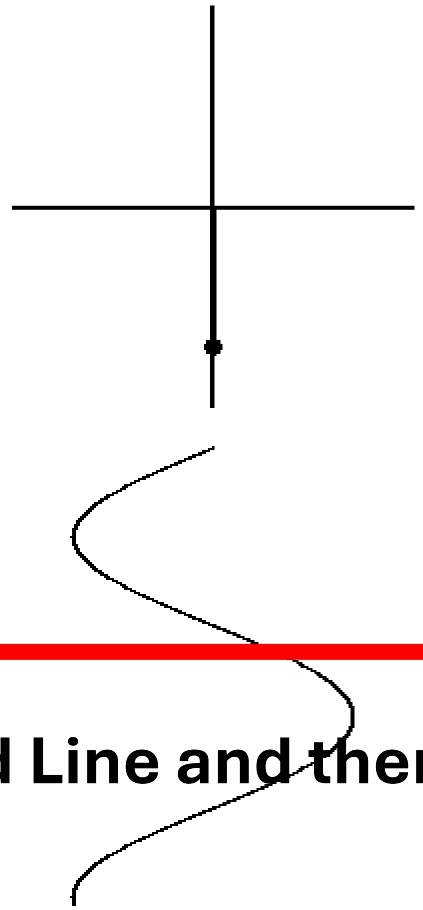
Energy basis

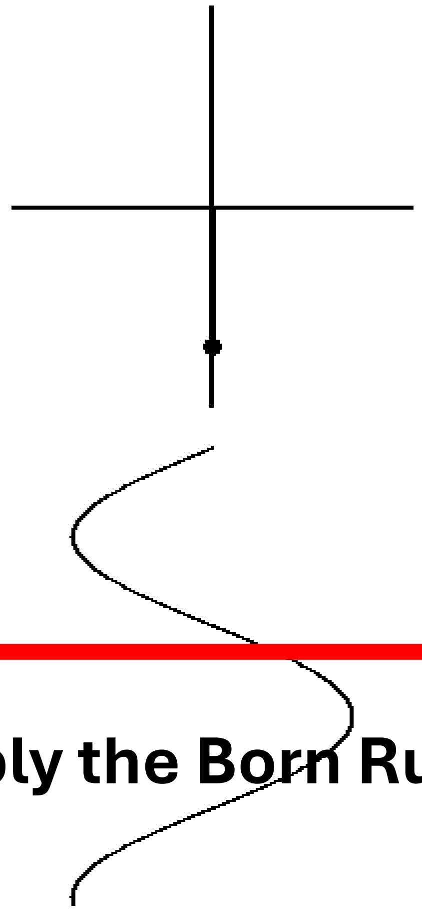
Momentum basis

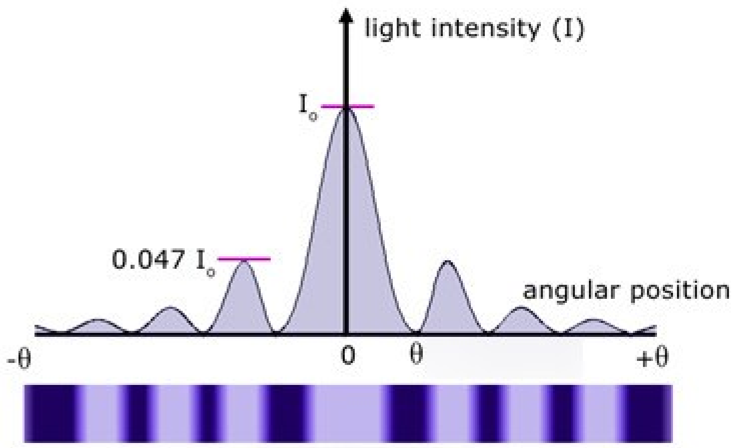
Spin basis

Position basis









Sum along the Red Line and then apply the Born Rule

HILBERT SPACE

Hilbert Space Is:

- the mathematical structure containing all allowed quantum states
- a structured possibility space
- a relational framework for quantum probabilities

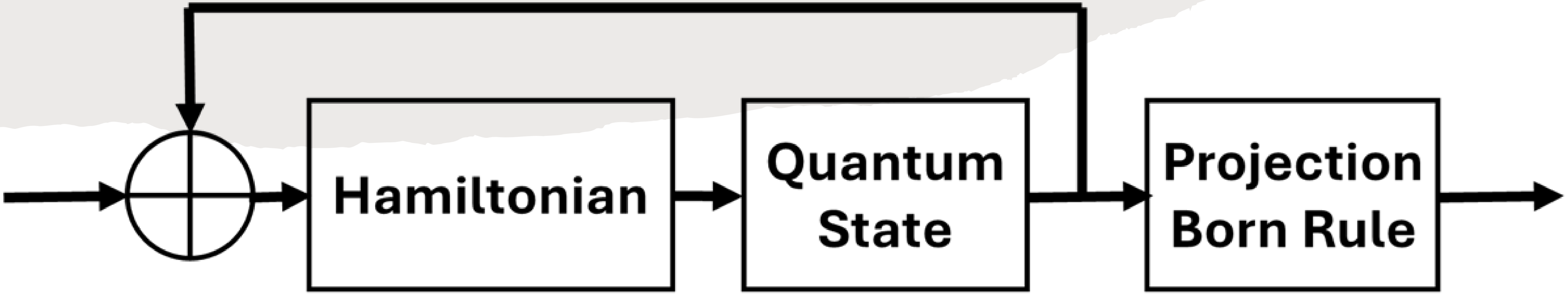
Hilbert Space Organizes:

- possible configurations
- probability amplitudes
- allowed quantum relationships
- constraints on probabilistic outcomes

Important:

Hilbert space can be understood philosophically as a structured space of possible becoming.

The Quantum State Machine Model



Hamiltonian / State Evolution

Process Theology Lens:

Superjective Nature

- lure toward patterned becoming
- emergence of ordered probabilities

Hilbert Space / Quantum States

Process Theology Lens:

Primordial Nature

- structured possibility
- constrained becoming
- ordered potentiality

Born Rule / Detector Events

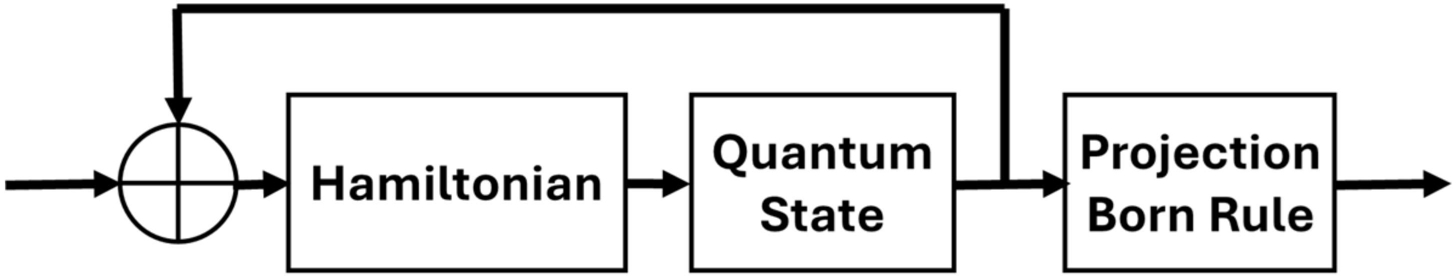
Process Theology Lens:

Consequent Nature

- realized actual occasions
- accumulated realized events

The model predicts probabilistic patterns across many actual occasions rather than predetermined individual events.

Looking Ahead



Quantum States and Hilber Space

This lecture focused on Structured Possibility (quantum states)

- superposition as a vector
- state vectors represent all possibilities
- Hilbert space
- changes of basis

These mathematical structures describe the possible outcomes of future detection events.

- But where do these quantum states come from?

In the next two lectures we will explore:

Lecture 4: Building the Quantum State Machine

Lecture 5: Running the Quantum State Machine

Central Question

How does a mathematical structure of possibilities become a model that predicts actual events?


"That's all Folks!"
Isberg©