

Title: Keynote Presentation on A Picture of Quantum Theory

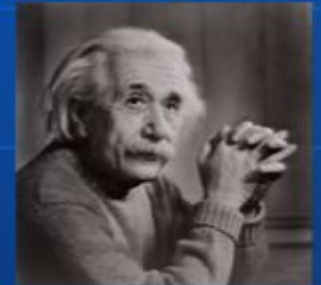
Date: Jul 04, 2006 01:00 PM

URL: <http://pirsa.org/06070002>

Abstract:



# Cats, Collapses and the Nature of Reality



What does quantum theory really mean?



# Einstein's reaction to quantum theory

Einstein spring 1927:

- i) Quantum theory does not yield the classical behavior of macroscopic objects to a good approximation.
- ii) Quantum theory leads to correlations among spatially separated objects that appear to violate action-by-contact principles.

# Outline

- Classical Physics in Configuration Space
- Quantum Physics in Configuration Space
- The Measurement Problem
- Different Interpretations
- Conclusion



*“Never underestimate the pleasure of  
hearing something you already know!”*

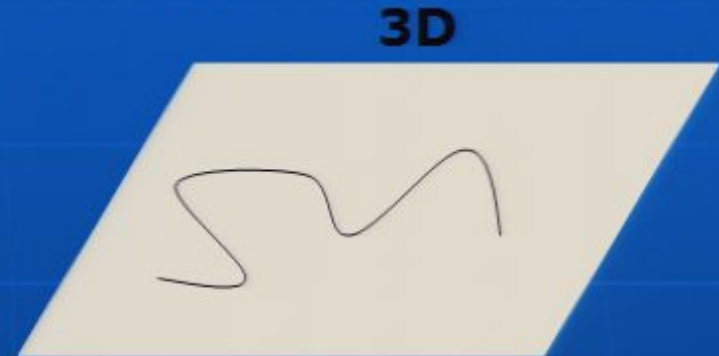
*Enrico Fermi*



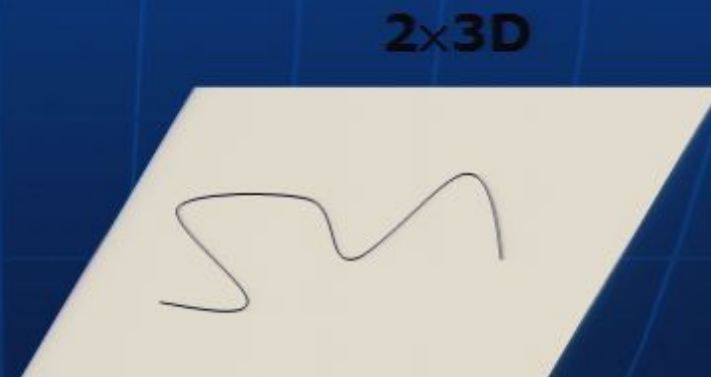
# Classical Physics

# Configuration Space

**One Particle:**  $\mathbf{X}=(x,y,z)$



**Two Particles:**  $\mathbf{X}=((x_1,y_1,z_1),(x_2,y_2,z_2))$



# Configuration Space

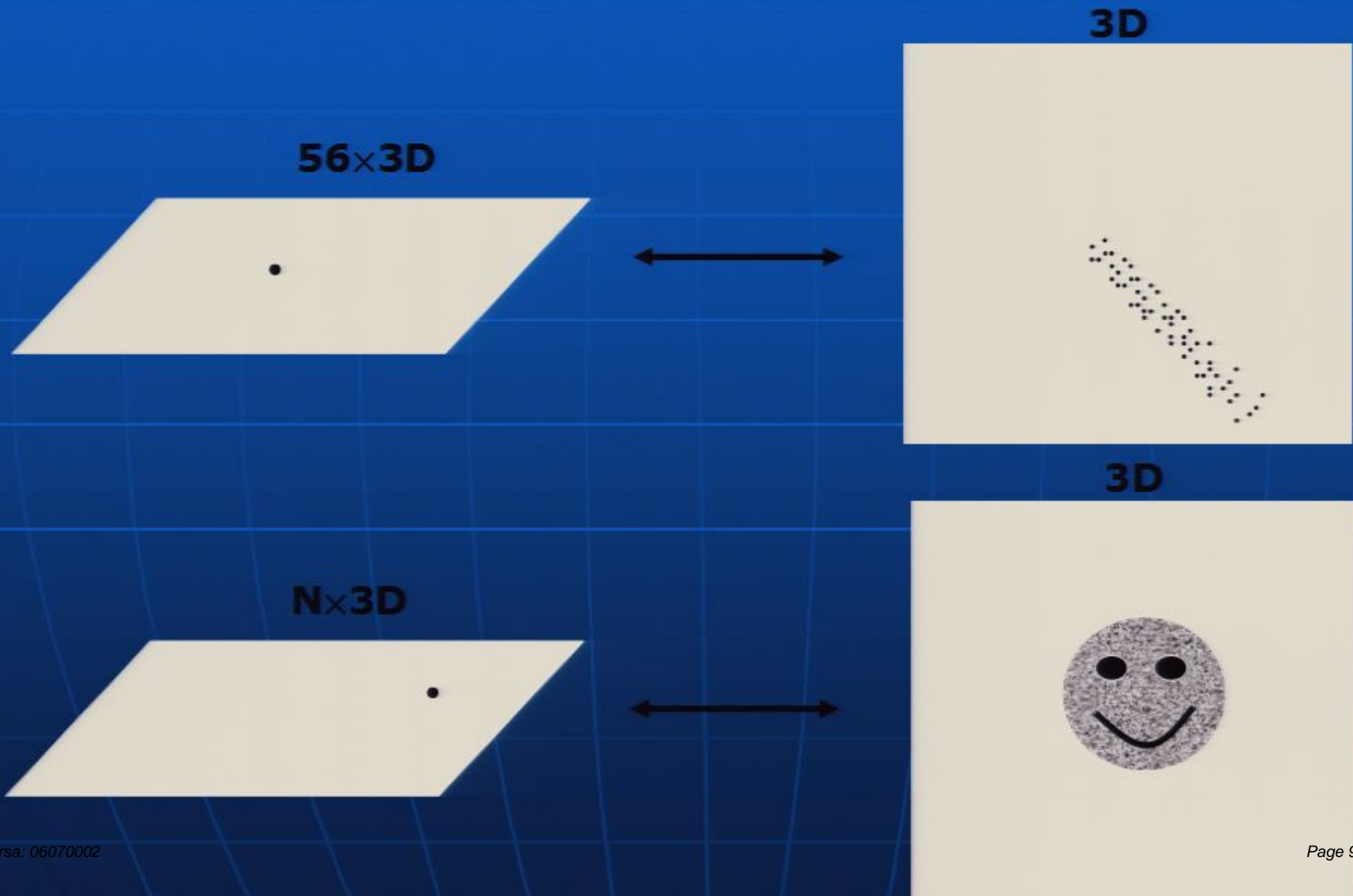
**N Particles:**  $\mathbf{X} = ((x_1, y_1, z_1), (x_2, y_2, z_2), \dots, (x_N, y_N, z_N))$

**N×3D**





# Correspondence to the Real World



# Short-Hand Notation

$$\mathbf{X} = ((x_1, y_1, z_1), (x_2, y_2, z_2), \dots, (x_N, y_N, z_N))$$

$N \times 3D$



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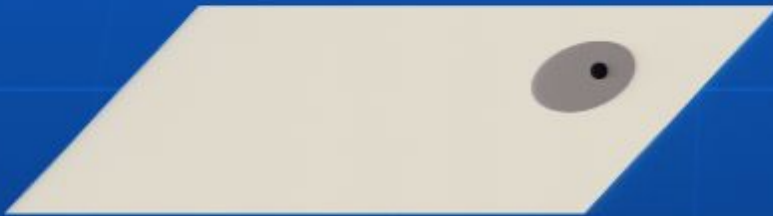
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# Evolution of the state $X$

$$X(0) = ((x_1(0), y_1(0), z_1(0)), \dots, (x_N(0), y_N(0), z_N(0)))$$

$N \times 3D$



$$X(t) = ((x_1(t), y_1(t), z_1(t)), \dots, (x_N(t), y_N(t), z_N(t)))$$

$N \times 3D$



$F = mA$



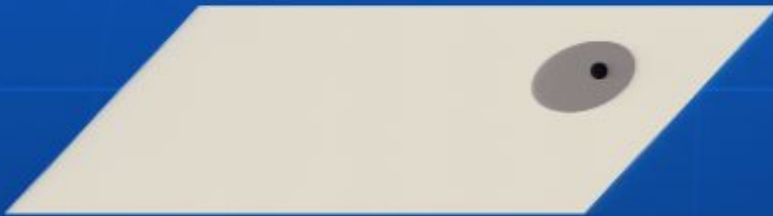
# Quantum Theory



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# Quantum Theory

# Quantum Theory: what's different?

Good News: we still have the good old configuration space!

$N \times 3D$



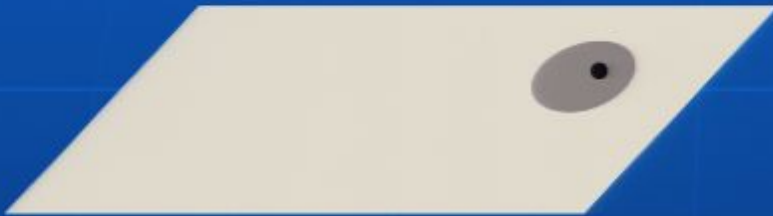
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A state in quantum theory is represented by a complex function  $\Psi(X)$  on configuration space, called the wave-function.

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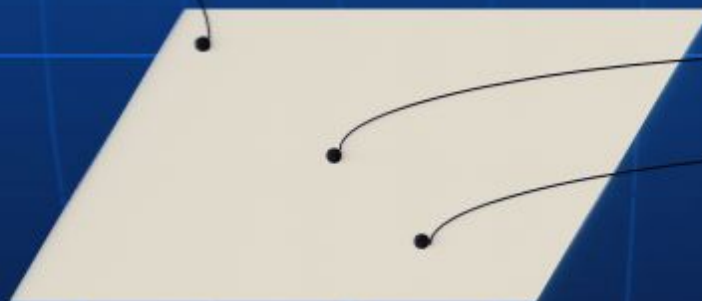
# The Wave-Function $\Psi$

$$\Psi((x_1, y_1, z_1), (x_2, y_2, z_2), \dots, (x_N, y_N, z_N))$$

Wave-function: Give me a point  $X$  in configuration space and I'll give you a complex number:  $a+bi$ .

0.000+0.00i

**N×3 D**



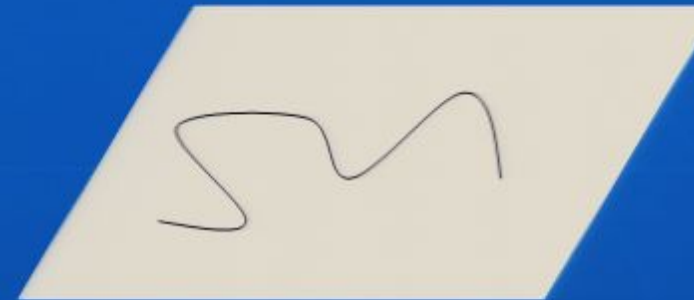
2.49834+4.458743i

3.452498+2.4389i

**3D**

**One Particle:**  $\mathbf{X}=(x,y,z)$

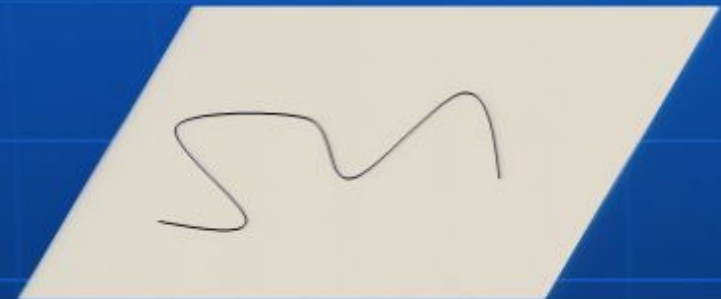
$$\Psi(x,y,z)$$



**Two Particles:**  $\mathbf{X}=((x_1,y_1,z_1),(x_2,y_2,z_2))$

$$\Psi((x_1,y_1,z_1),(x_2,y_2,z_2))$$

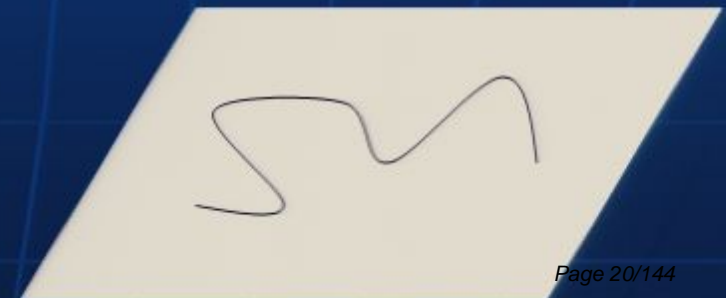
**2x3D**



**N Particles:**  $\mathbf{X}=((x_1,y_1,z_1),(x_2,y_2,z_2),\dots,(x_N,y_N,z_N))$

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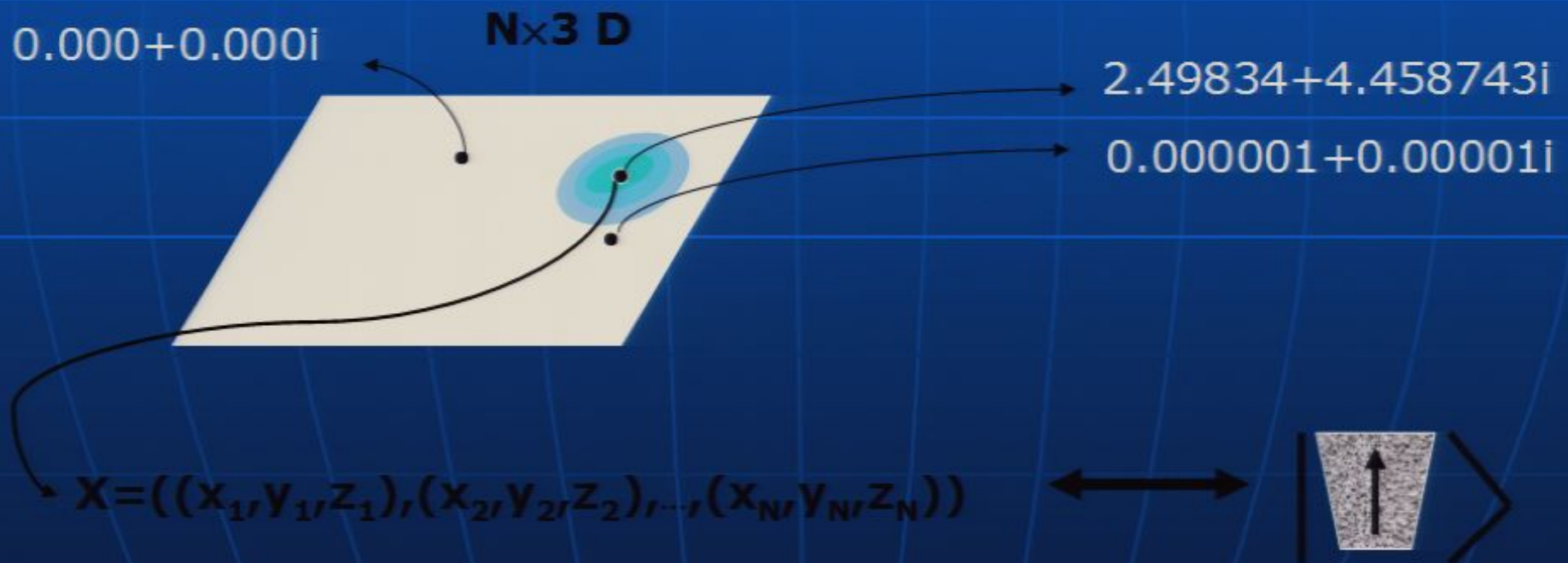




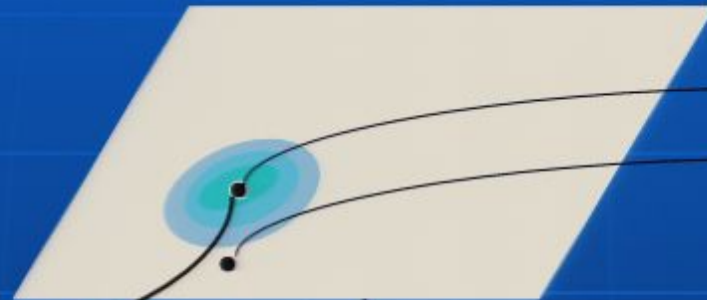
We are going to assume that quantum theory is fundamental and applies to everything, even macroscopic bodies and not just atoms and electrons.

# Correspondence to Reality

Assume that we have a wave-function that is “peaked” around some point  $X$  in configuration space.



**$N \times 3 \text{ D}$**



$$2.49834 + 4.458743i$$

$$0.000001 + 0.000001i$$

$$\Psi(X) = 0$$

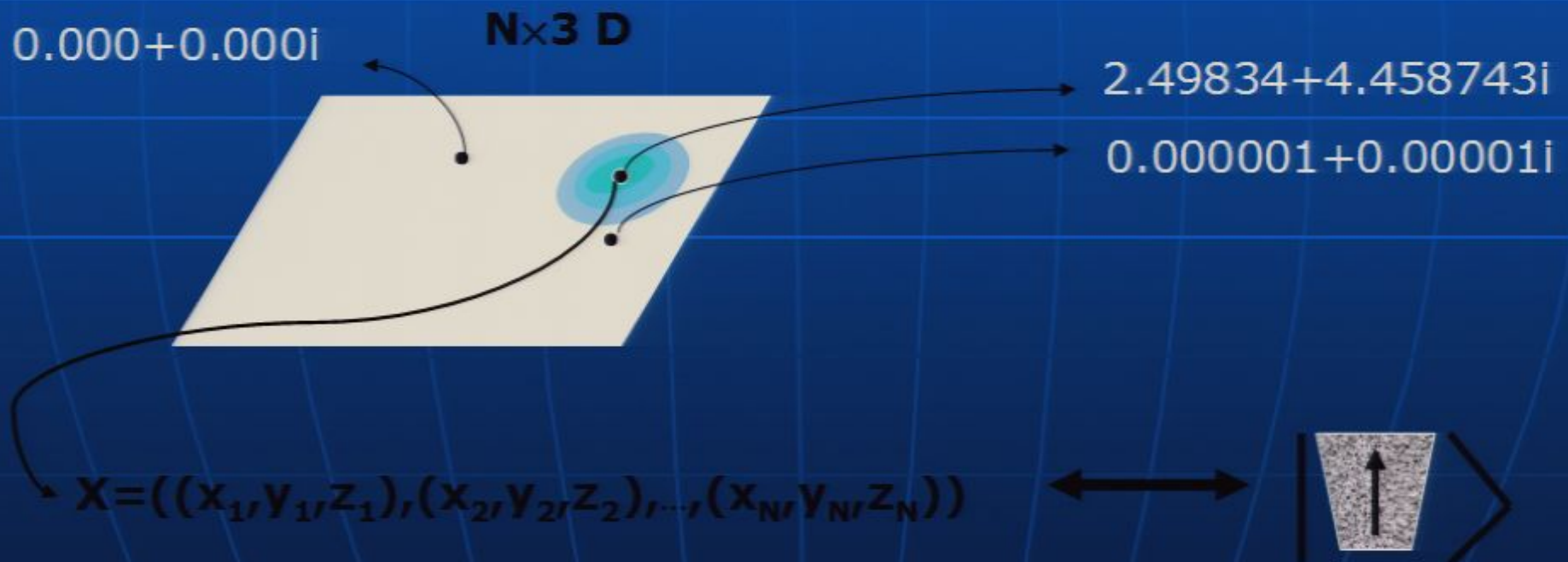
$$X = ((x_1, y_1, z_1), (x_2, y_2, z_2), \dots, (x_N, y_N, z_N))$$





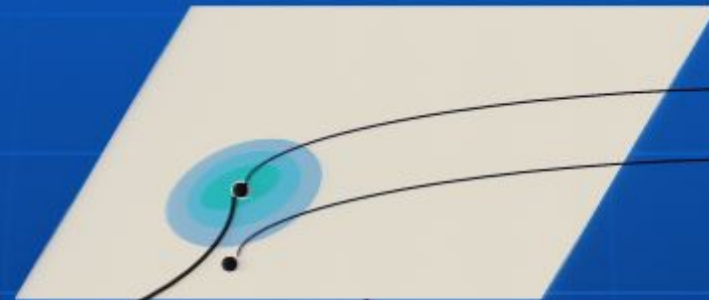
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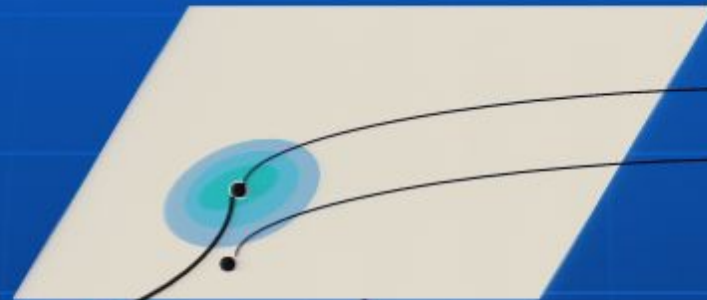
# Superposition Principle I

If  $\Psi_1$  and  $\Psi_2$  are possible quantum states then also

$$\alpha\Psi_1 + \beta\Psi_2$$

is a possible quantum state.

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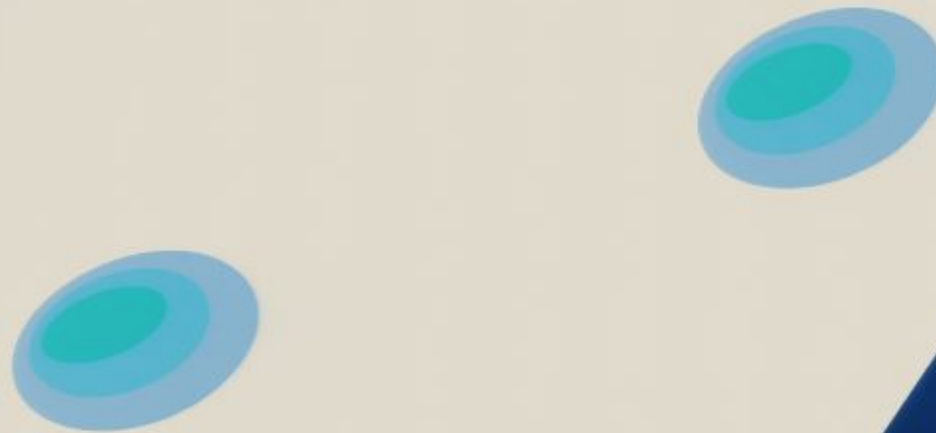
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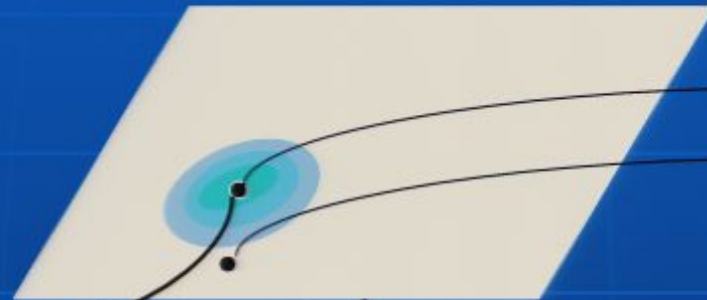
# This is troubling...

$$\alpha \left| \begin{array}{c} \text{trapezoid} \\ \uparrow \end{array} \right\rangle + \beta \left| \begin{array}{c} \text{trapezoid} \\ \nwarrow \end{array} \right\rangle \quad ???$$

**N×3 D**



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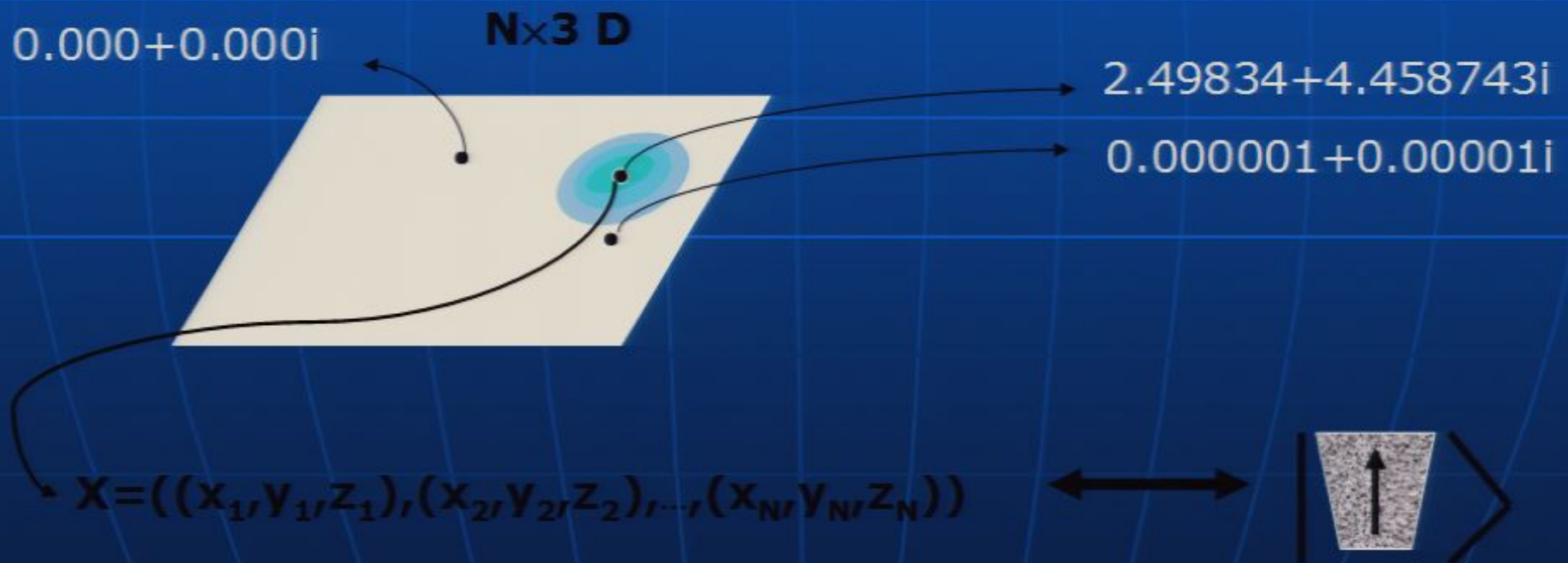
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$$X=((x_1, y_1, z_1), (x_2, y_2, z_2), \dots, (x_N, y_N, z_N)) \longleftrightarrow \left| \begin{array}{c} \text{trapezoid with arrow} \end{array} \right\rangle$$

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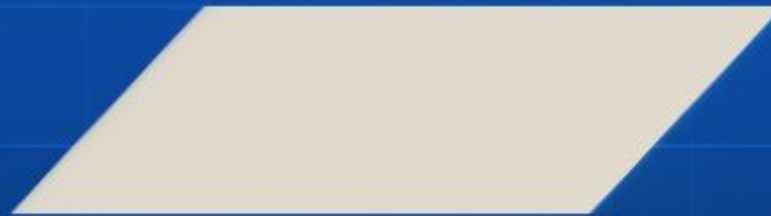
# Quantum Theory



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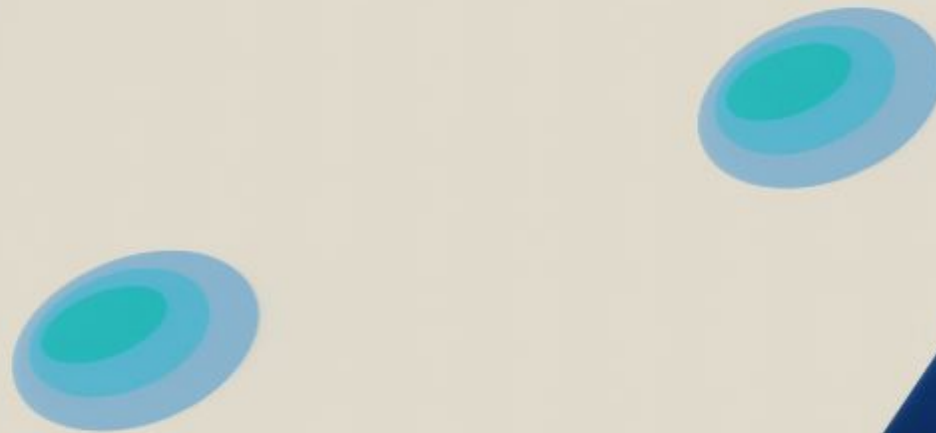
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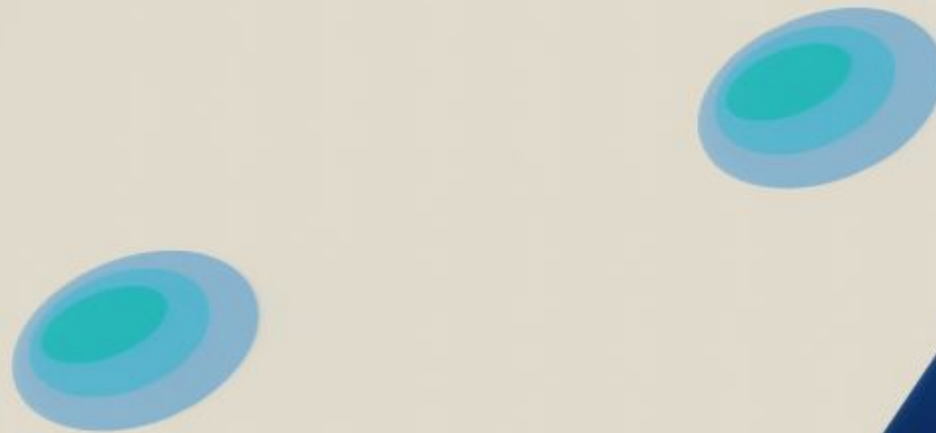
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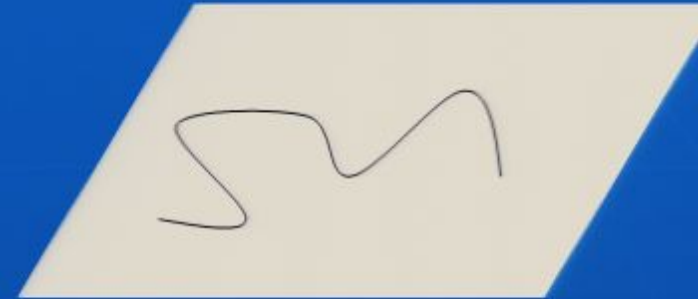
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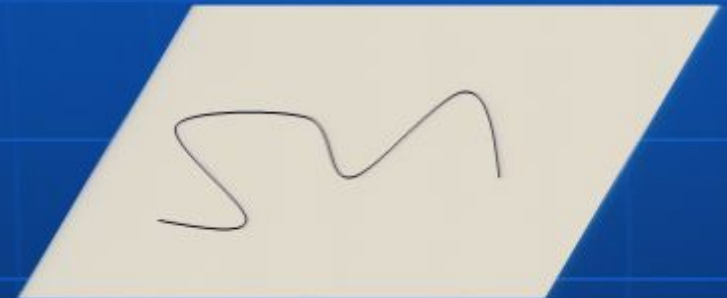
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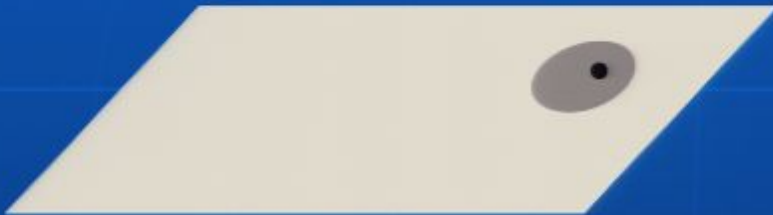
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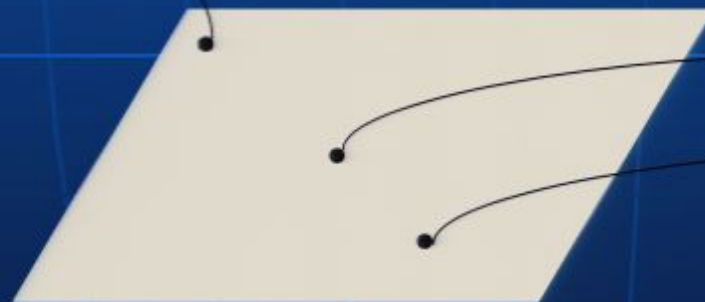
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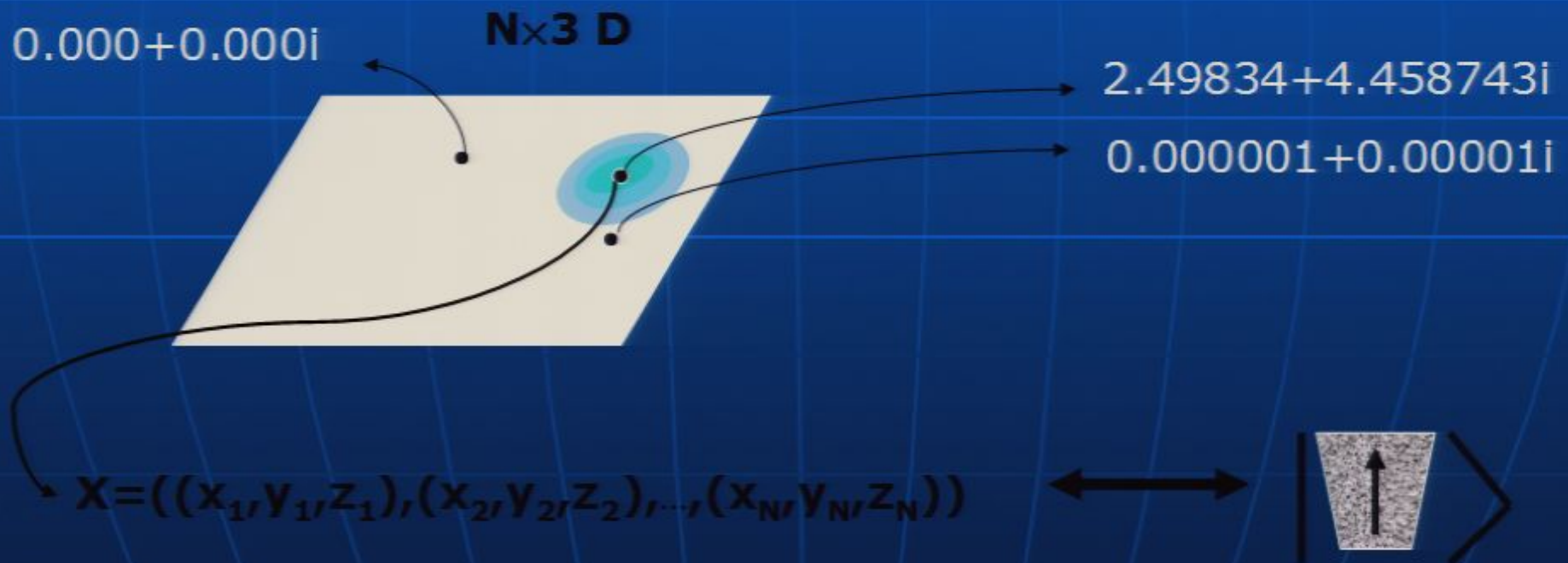


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# Correspondence to Reality

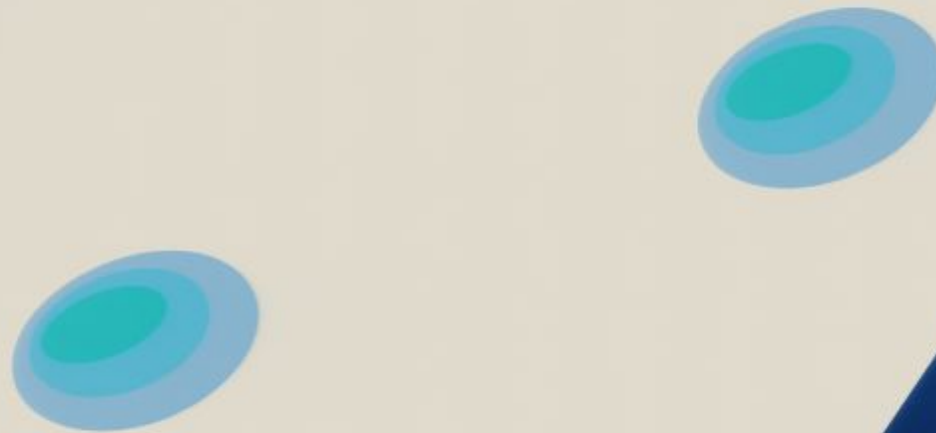
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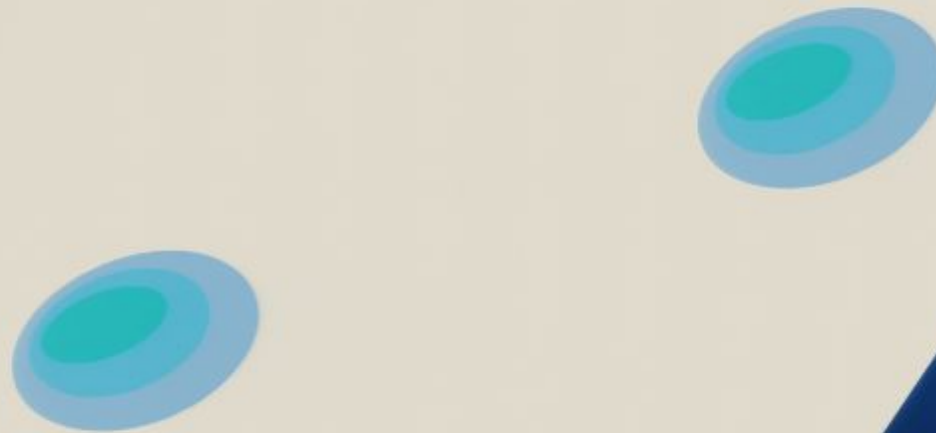
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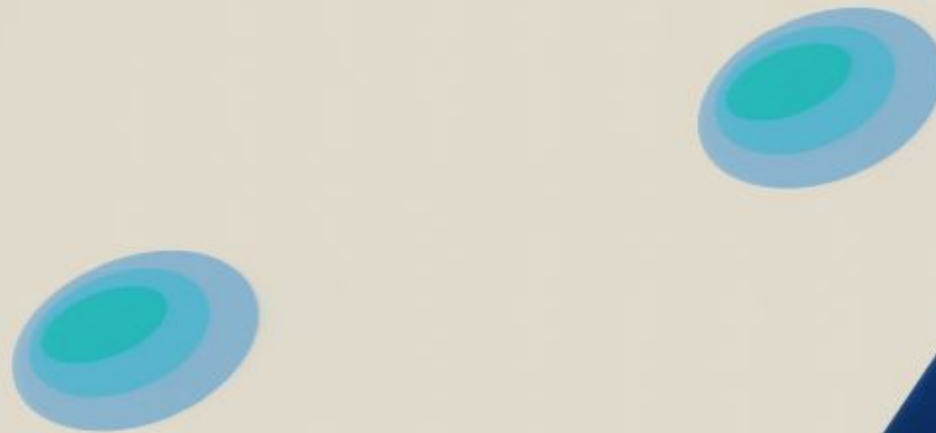
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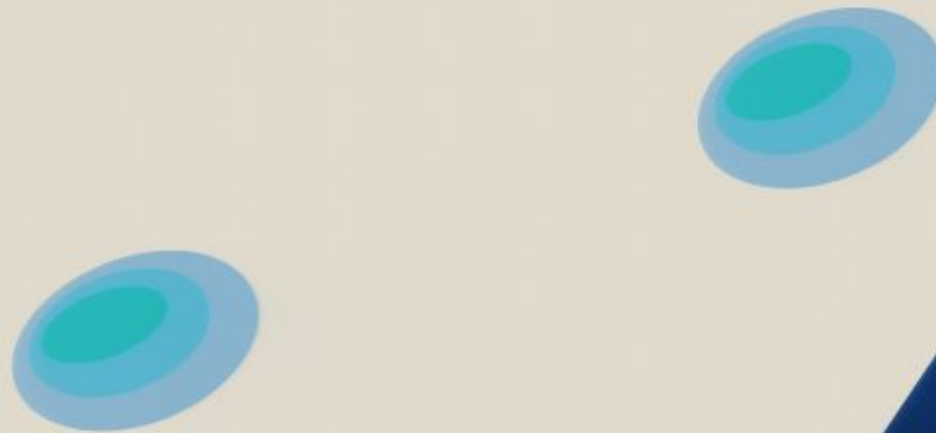
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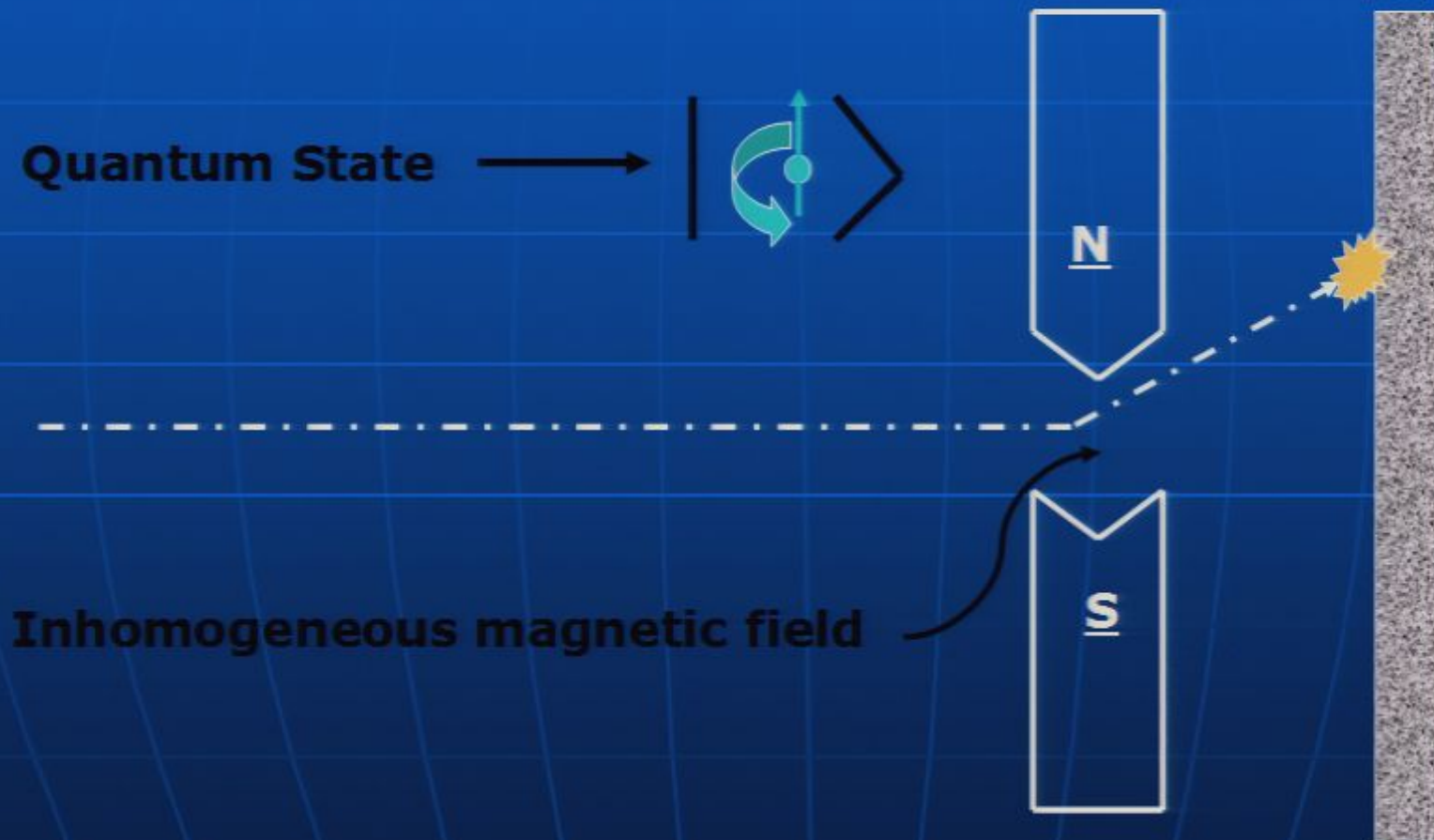
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# Quantum Measurement Theory

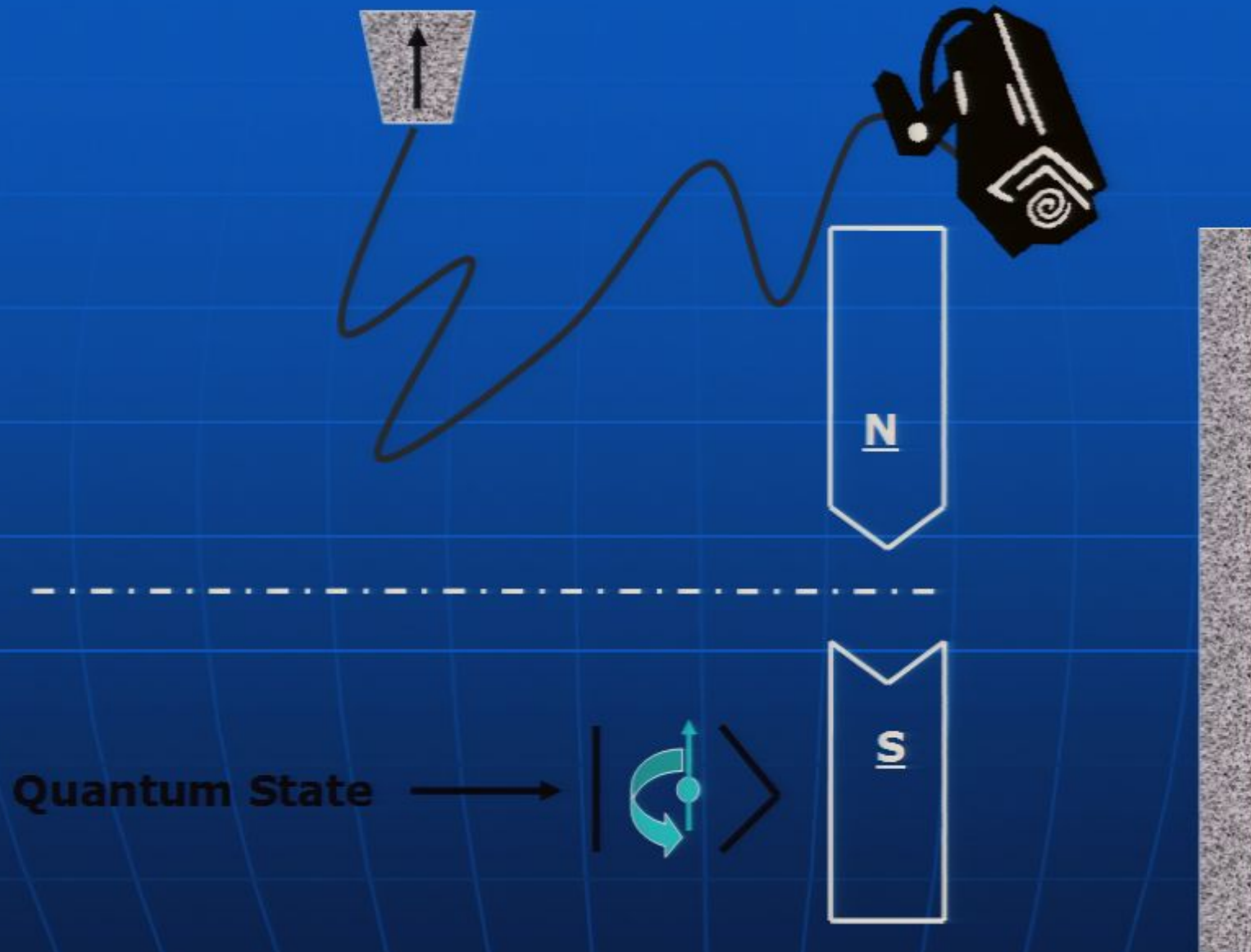
Example: measurement of spin





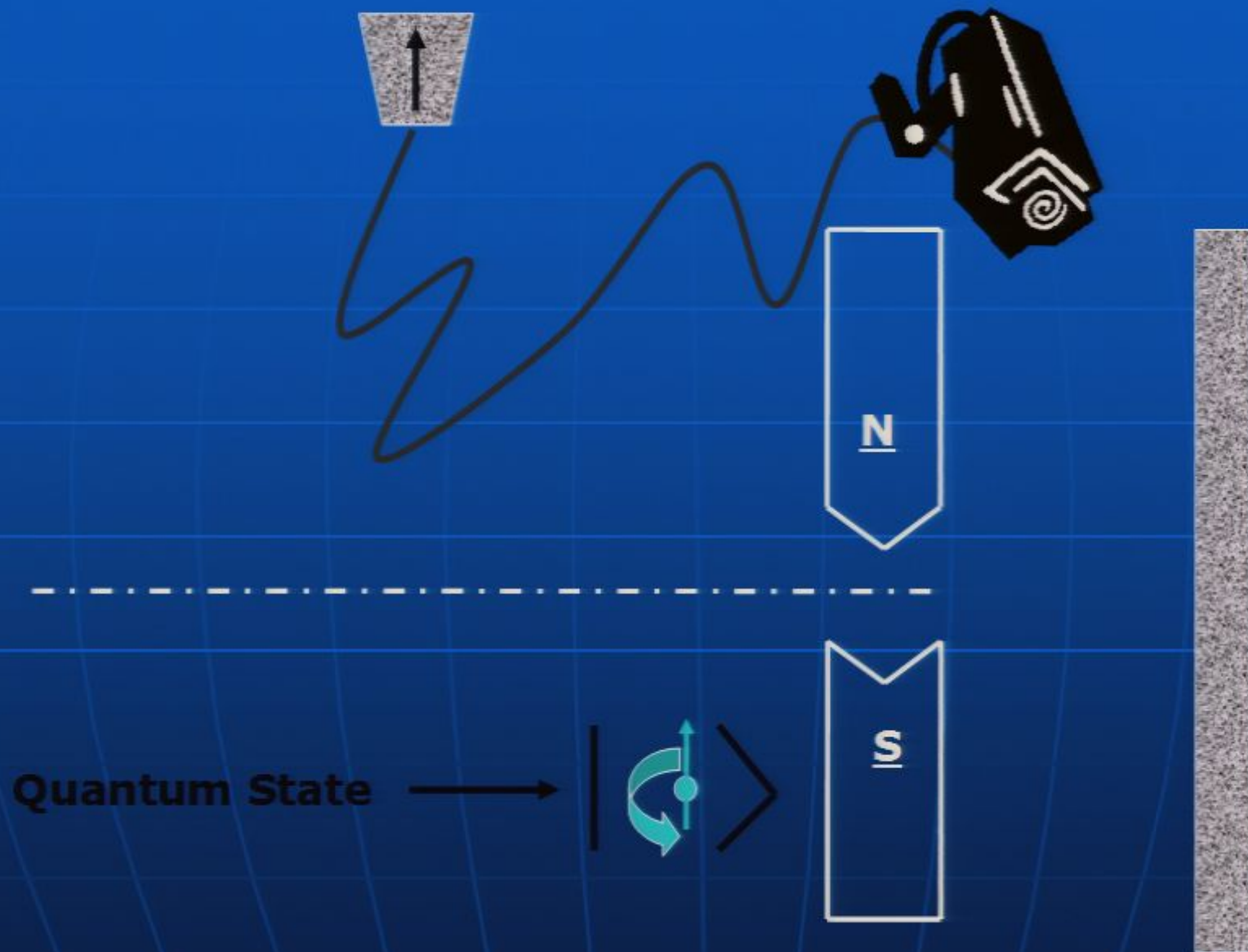
Quantum State



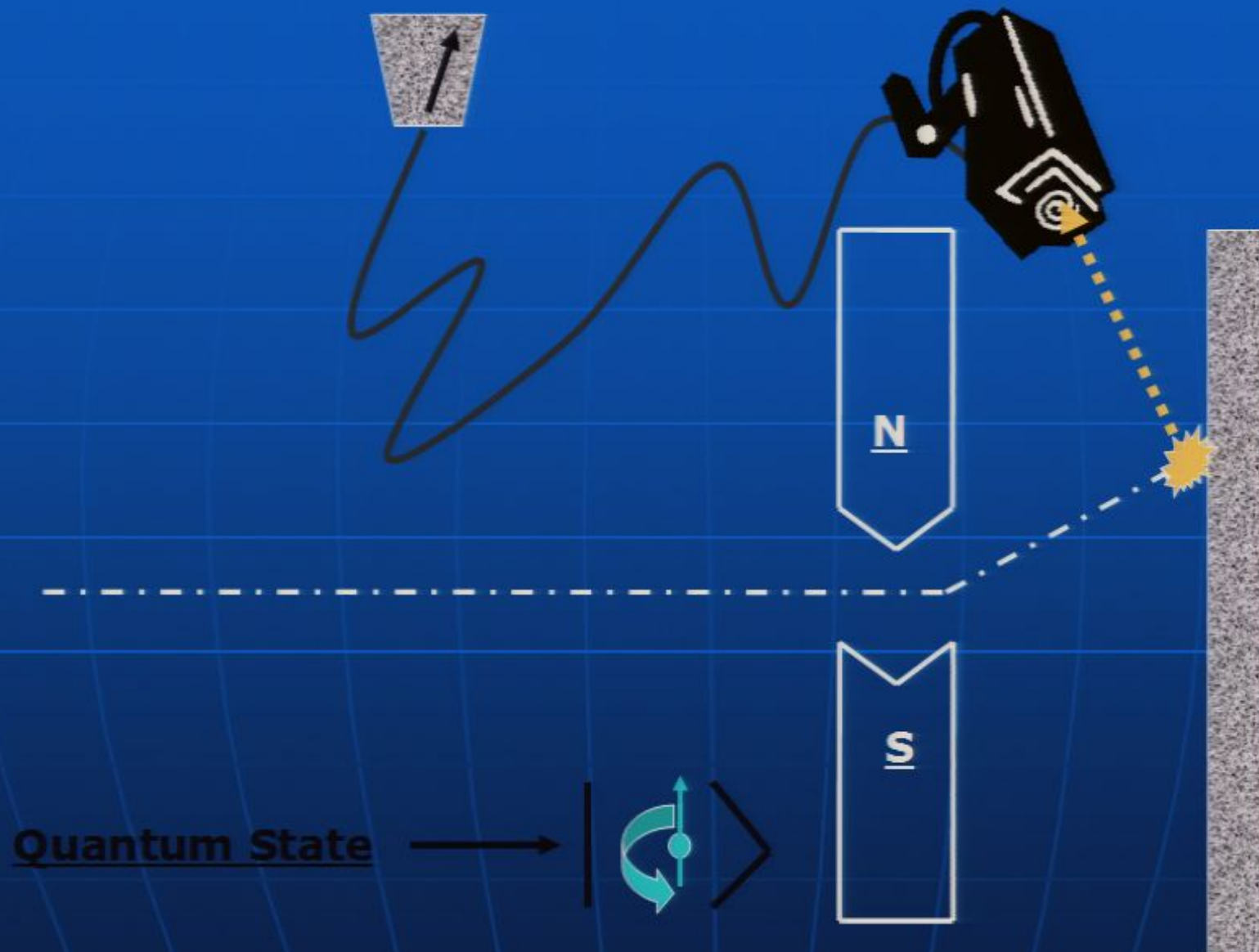


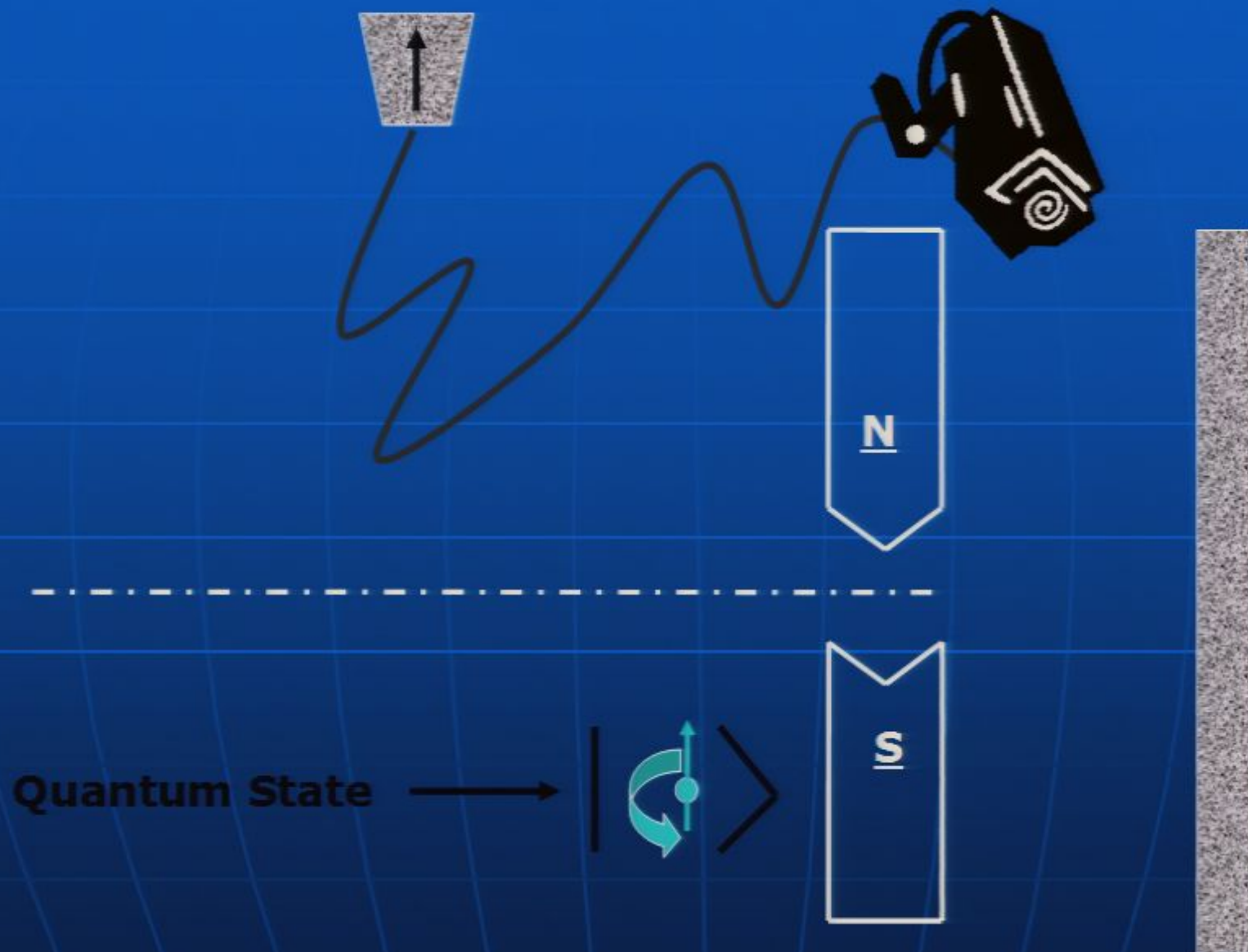
Quantum State

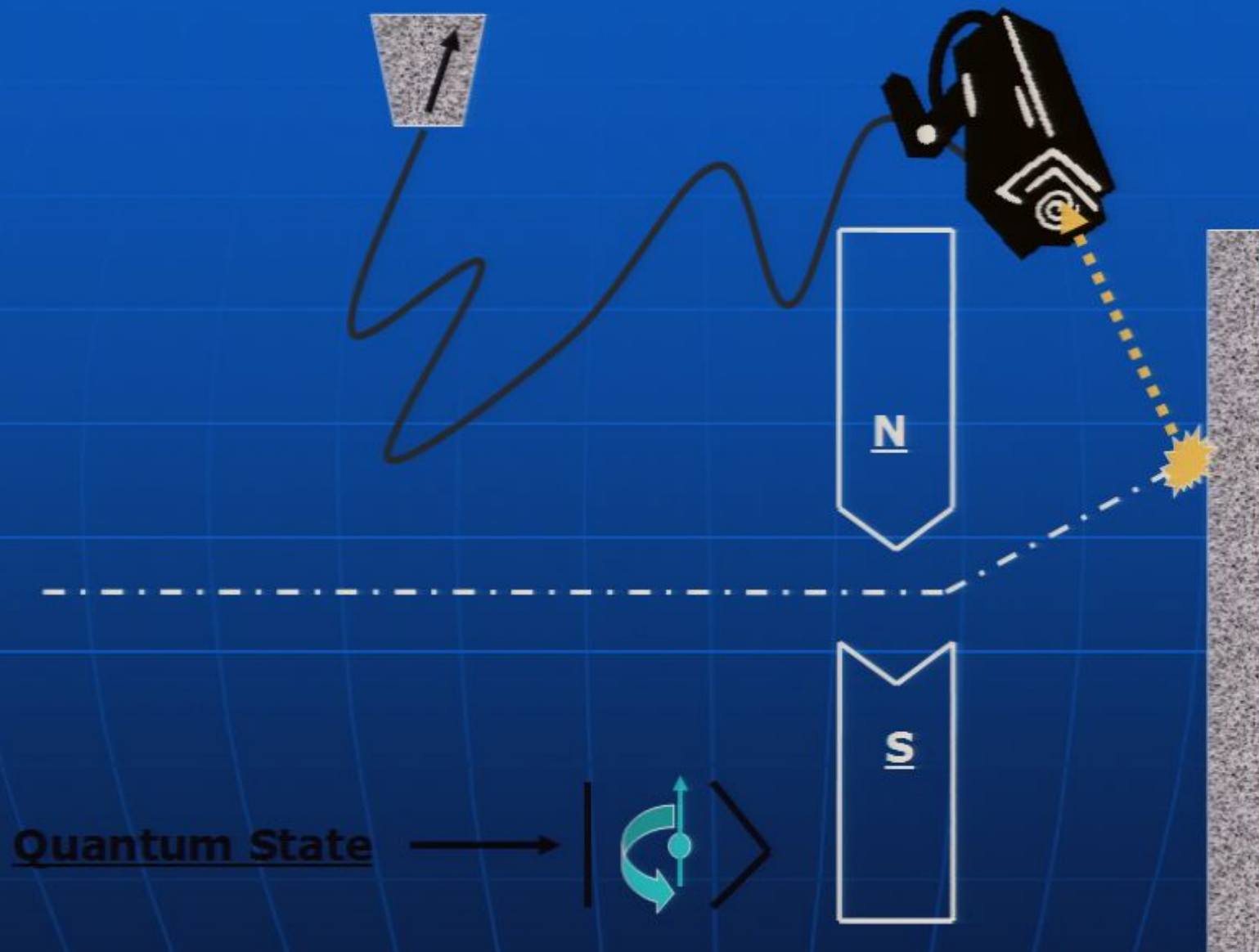


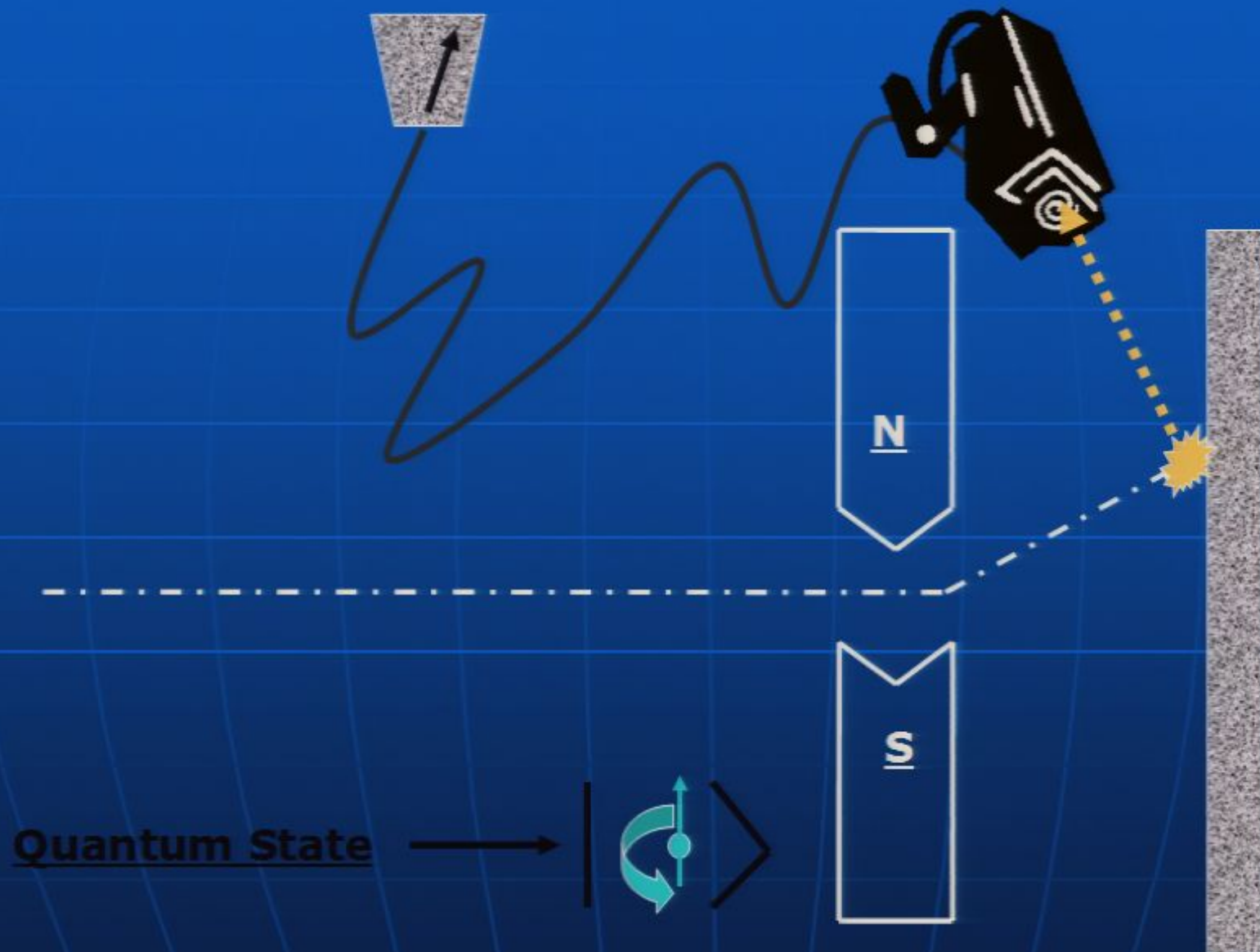




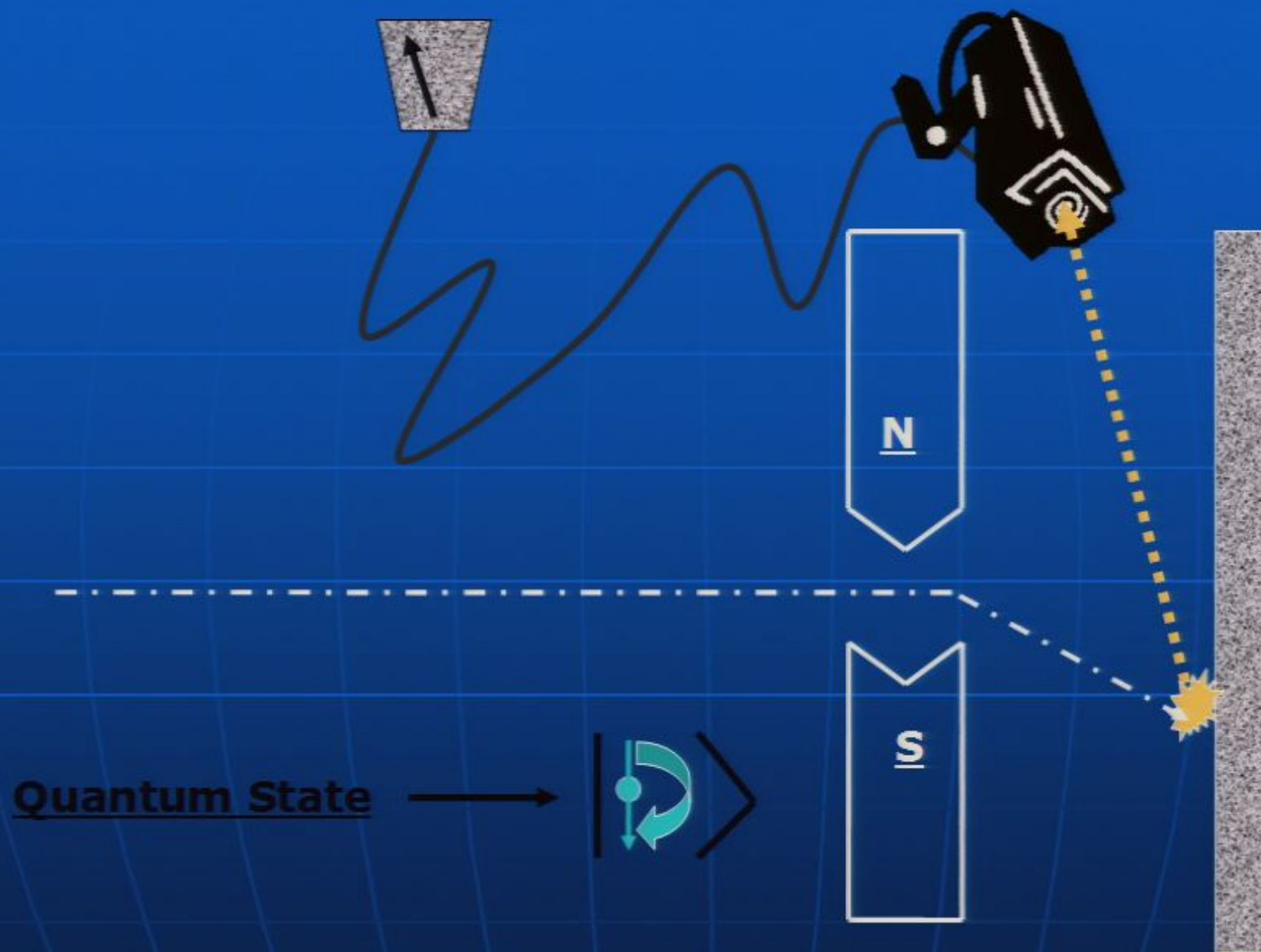












# Evolution of the quantum state

Ideal Experiment:



# Superposition Principle II

If two quantum states evolve according to:

$$\Psi_1 \longrightarrow \Phi_1$$

$$\Psi_2 \longrightarrow \Phi_2$$

Then the super position  $\alpha\Psi_1 + \beta\Psi_2$  will evolve according to:

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# The Measurement Problem

According to Superposition Principle I  
the state

$$\alpha \left| \begin{array}{c} \text{trapezoid} \\ \uparrow \end{array} \right\rangle \left| \begin{array}{c} \text{blue dot} \\ \uparrow \end{array} \right\rangle + \beta \left| \begin{array}{c} \text{trapezoid} \\ \uparrow \end{array} \right\rangle \left| \begin{array}{c} \text{blue dot} \\ \downarrow \end{array} \right\rangle$$

is a possible quantum state.

It is not a “strange” state since it is only the electron which is in a superposition of “spin up” and “spin down”.

In fact, this quantum state is routinely created in laboratories.

According to Superposition Principle II  
the state has to evolve according to:

$$\alpha \left| \begin{array}{c} \text{trapezoid} \\ \uparrow \end{array} \right\rangle \left| \begin{array}{c} \text{circle} \\ \updownarrow \end{array} \right\rangle + \beta \left| \begin{array}{c} \text{trapezoid} \\ \uparrow \end{array} \right\rangle \left| \begin{array}{c} \text{circle} \\ \downarrow \uparrow \end{array} \right\rangle$$



$$\alpha \left| \begin{array}{c} \text{trapezoid} \\ \nearrow \end{array} \right\rangle \left| \begin{array}{c} \text{circle} \\ \updownarrow \end{array} \right\rangle + \beta \left| \begin{array}{c} \text{trapezoid} \\ \nwarrow \end{array} \right\rangle \left| \begin{array}{c} \text{circle} \\ \downarrow \uparrow \end{array} \right\rangle$$

# But now we are in trouble!

The state

$$\alpha \left| \begin{array}{c} \text{trapezoid} \\ \nearrow \end{array} \right\rangle \left| \begin{array}{c} \text{circular arrow} \\ \uparrow \end{array} \right\rangle + \beta \left| \begin{array}{c} \text{trapezoid} \\ \nwarrow \end{array} \right\rangle \left| \begin{array}{c} \text{circular arrow} \\ \downarrow \end{array} \right\rangle$$

is a superposition of two macroscopically distinct states!



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$$\Psi_2 \longrightarrow \Phi_2$$

Then the super position  $\alpha\Psi_1 + \beta\Psi_2$  will evolve according to:

$$\alpha\Psi_1 + \beta\Psi_2 \longrightarrow \alpha\Phi_1 + \beta\Phi_2$$

According to Superposition Principle II  
the state has to evolve according to:

$$\alpha \left| \begin{array}{c} \text{trapezoid} \\ \uparrow \end{array} \right\rangle \left| \begin{array}{c} \text{circle} \\ \updownarrow \end{array} \right\rangle + \beta \left| \begin{array}{c} \text{trapezoid} \\ \uparrow \end{array} \right\rangle \left| \begin{array}{c} \text{circle} \\ \downarrow \end{array} \right\rangle$$



$$\alpha \left| \begin{array}{c} \text{trapezoid} \\ \nearrow \end{array} \right\rangle \left| \begin{array}{c} \text{circle} \\ \updownarrow \end{array} \right\rangle + \beta \left| \begin{array}{c} \text{trapezoid} \\ \nwarrow \end{array} \right\rangle \left| \begin{array}{c} \text{circle} \\ \downarrow \end{array} \right\rangle$$

# But now we are in trouble!

The state

$$\alpha \nearrow \rangle | \text{clockwise} \rangle + \beta \text{trapezoid} \rangle | \text{counterclockwise} \rangle$$

is a superposition of two macroscopically distinct states!



In a quantum experiment the state  
will in general evolve into a strange  
superposition of two  
macroscopically distinct states!

*According to quantum theory it is not  
only electrons that can be here and  
there at the same time! Also macroscopic  
objects like the measurement equipment,  
... and human beings...*

... or cats...

$$\alpha \left| \text{cat}_1 \right\rangle \left| \uparrow \right\rangle + \beta \left| \text{cat}_2 \right\rangle \left| \downarrow \right\rangle$$

# Different Reactions

"Shut Up! and Calculate" Interpretation

Copenhagen Interpretation

Von Neumann-Dirac Collapse Interpretation

Many Worlds Interpretation

Quantum Information Interpretation

Hidden Variable Interpretation



# Copenhagen Interpretation

- The world should be divided into two parts: the quantum system one is measuring, and the classical apparatus that is doing the measuring
- The quantum system should be treated according to quantum theory
- The apparatus should be treated according to classical physics.
- The interaction between a quantum system and a classical system (i.e the measurement process) is regarded as **unanalyzable**. One cannot give a precise scientific description of what is going on in a measurement process.



# Problems

- How do I know what is a quantum system and what is a classical apparatus? A classical apparatus is made out of atoms! How many atoms do I need in order to be sure that it is a classical system?
- No satisfactory answer given by Bohr.
- And isn't it non-scientific to claim that it is scientifically impossible to analyze what happens during a measuring process?

# Von Neumann & Dirac

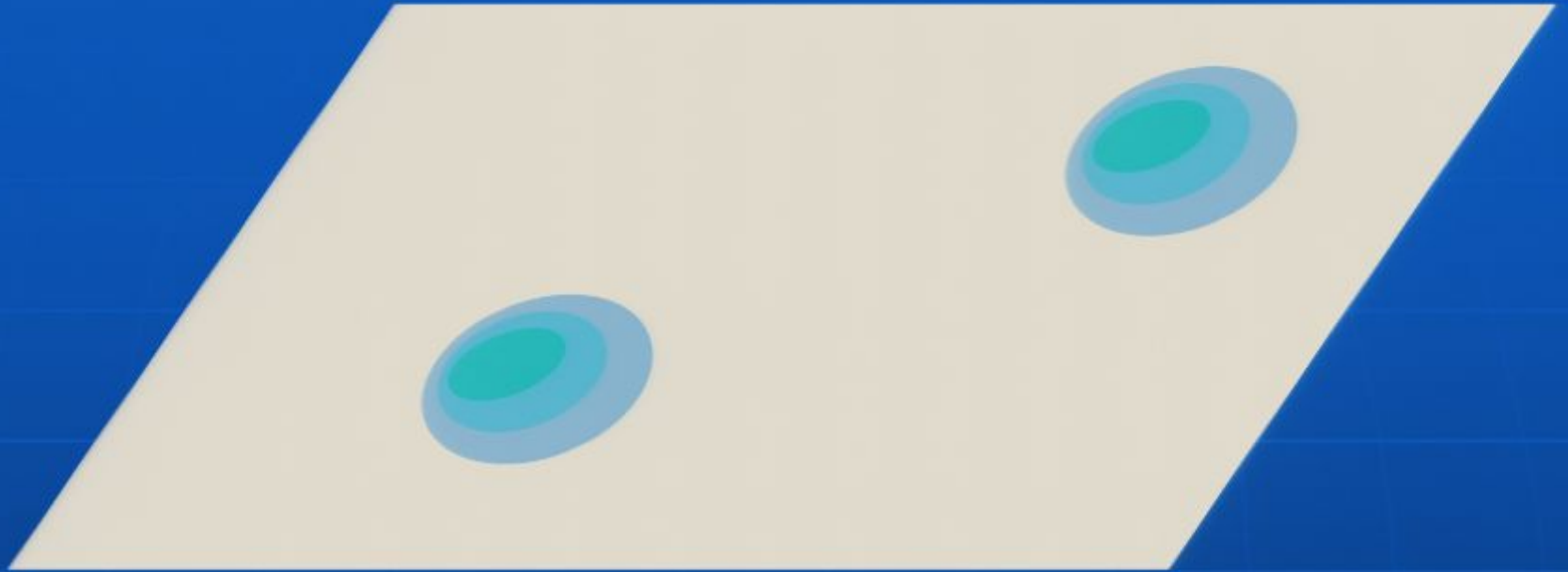
- When macroscopic bodies are involved the wave-function

$$\alpha \left| \text{trapezoid with up arrow} \right\rangle \left| \text{clockwise rotation} \right\rangle + \beta \left| \text{trapezoid with up arrow} \right\rangle \left| \text{counter-clockwise rotation} \right\rangle$$

Collapses into

$$\alpha \left| \text{trapezoid with up arrow} \right\rangle \left| \text{clockwise rotation} \right\rangle \text{ OR } \beta \left| \text{trapezoid with up arrow} \right\rangle \left| \text{counter-clockwise rotation} \right\rangle$$

$N \times 3 \text{ D}$



Collapse



$N \times 3 \text{ D}$



$N \times 3 \text{ D}$



OR



# Problems

- If the wave-function collapses then when is this supposed to occur? How big must a “classical” apparatus be in order for a collapse to occur?
- And where are the mathematical equations that tell me EXACTLY how and when the wave-function collapses?



# Collapse theories

- Pearle, Ghirardi, Rimini, Weber, modified quantum theory. Collapse is a physical process.
- Energy is not conserved.
- Fully relativistic collapse theories are difficult to make: infinite energy production per unit time!
- “Almost”-relativistic ones are possible to construct (Pearle).

# Many Worlds

- Let's take quantum theory REALLY seriously and fully accept these strange superpositions.

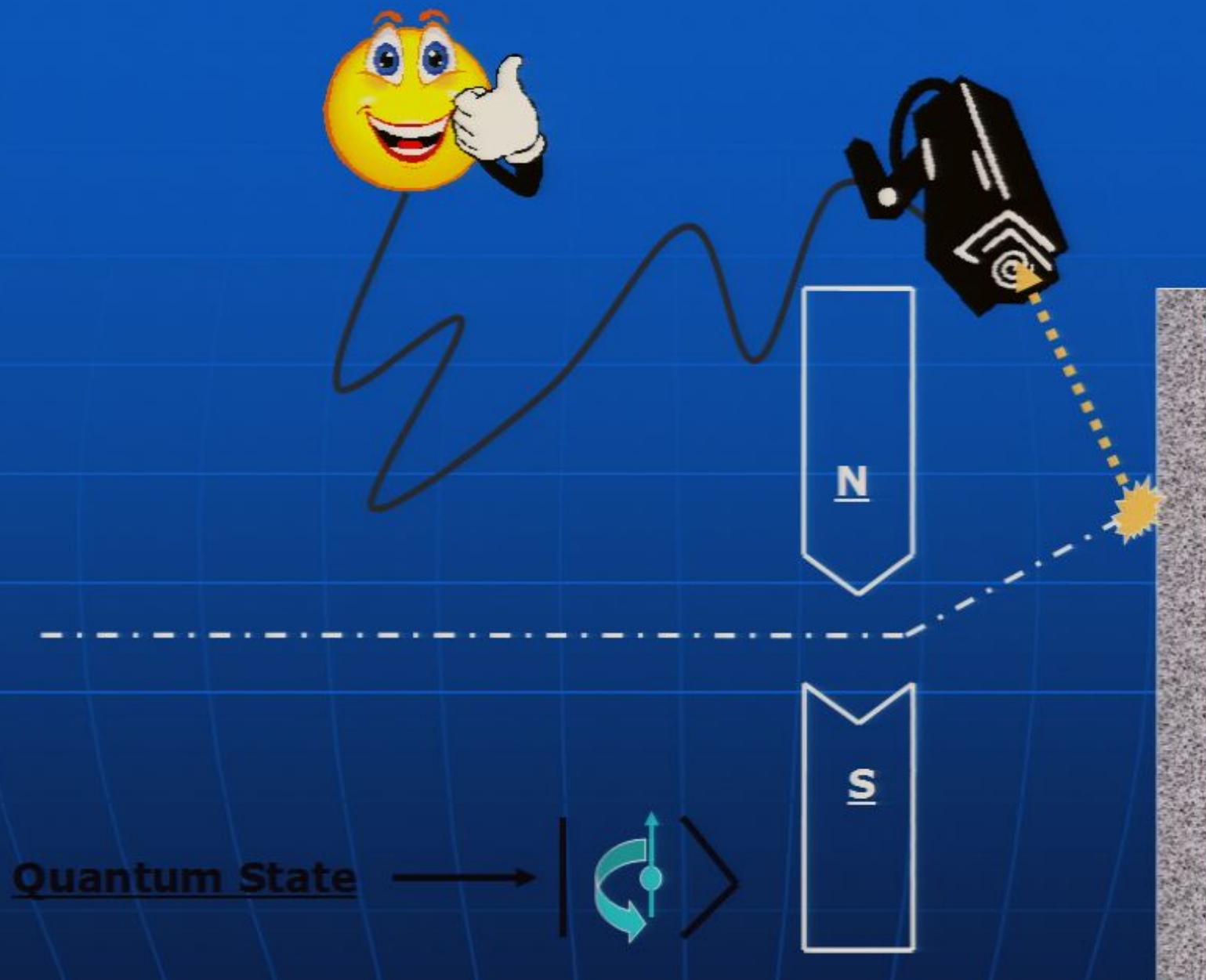
$$\alpha \left| \begin{array}{c} \text{trapezoid with upward arrow} \end{array} \right\rangle \left| \begin{array}{c} \text{blue circle with up arrow} \end{array} \right\rangle + \beta \left| \begin{array}{c} \text{trapezoid with downward arrow} \end{array} \right\rangle \left| \begin{array}{c} \text{blue circle with down arrow} \end{array} \right\rangle$$



Quantum State





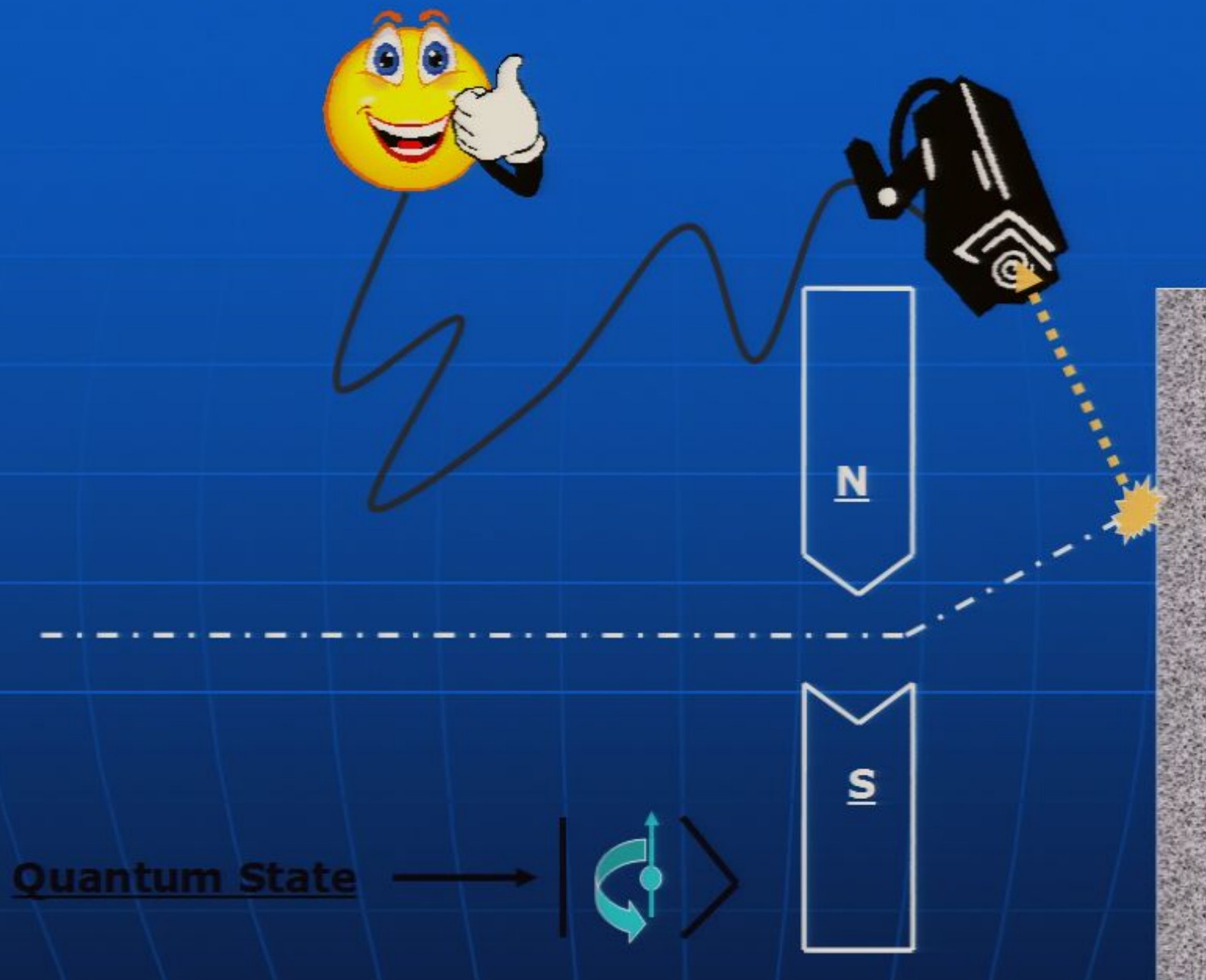






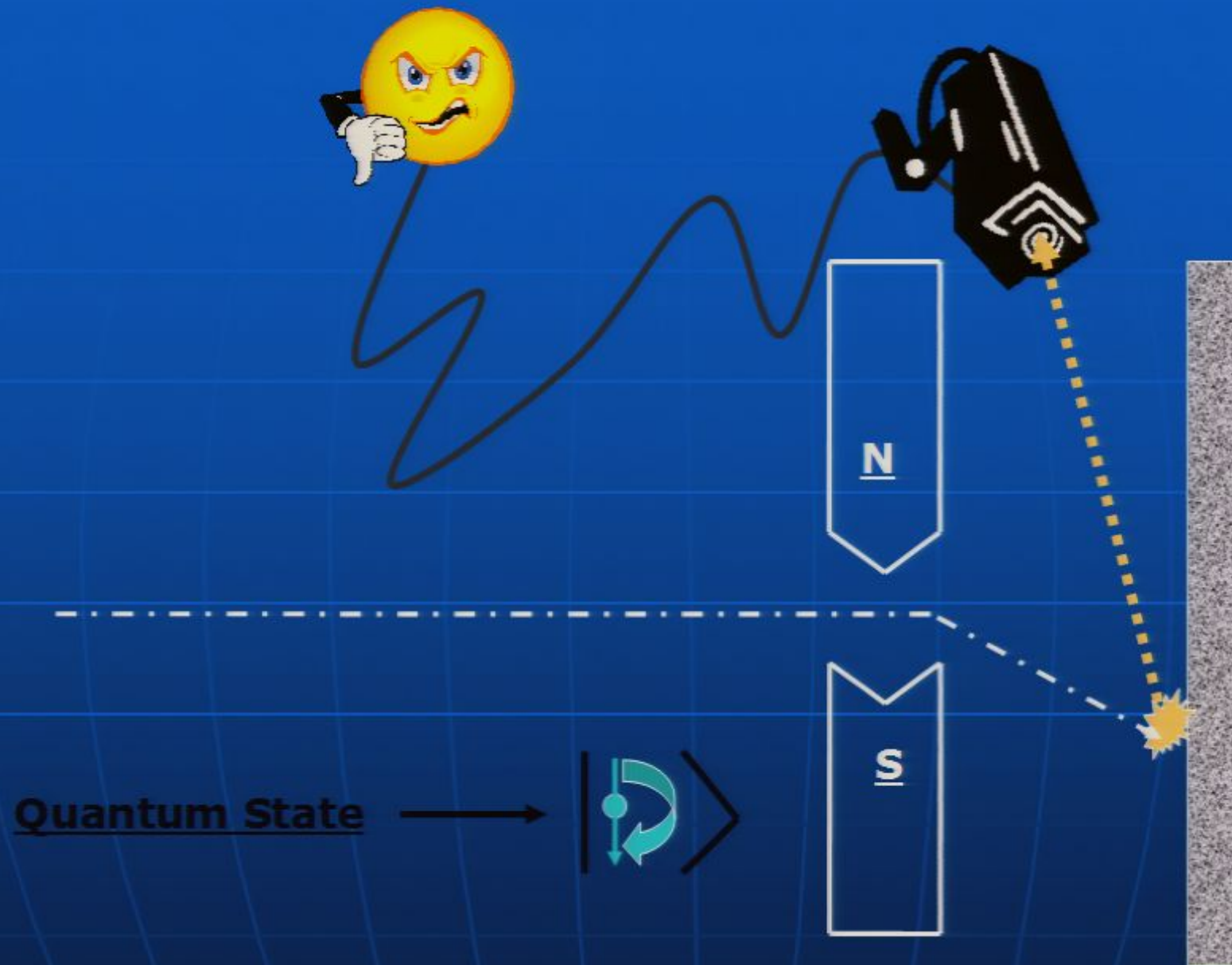
Quantum State





Quantum State





$$\alpha \left| \text{👓} \right\rangle \left| \text{👉} \right\rangle \left| \text{🔄} \right\rangle + \beta \left| \text{👓} \right\rangle \left| \text{👉} \right\rangle \left| \text{🔄} \right\rangle$$



$$\alpha \left| \text{👍} \right\rangle \left| \text{👉} \right\rangle \left| \text{🔄} \right\rangle + \beta \left| \text{👎} \right\rangle \left| \text{👉} \right\rangle \left| \text{🔄} \right\rangle$$



# Problems

- Hard to understand why we see quantum statistics.
- Preferred basis problem: how can we identify the different worlds in the wave-function?
- We can never verify that these parallel worlds are really “out there”.

$$\alpha \left| \text{👓} \right\rangle \left| \text{👉} \right\rangle \left| \text{🔄} \right\rangle + \beta \left| \text{👓} \right\rangle \left| \text{👉} \right\rangle \left| \text{🔄} \right\rangle$$



$$\alpha \left| \text{👍} \right\rangle \left| \text{👉} \right\rangle \left| \text{🔄} \right\rangle + \beta \left| \text{👎} \right\rangle \left| \text{👉} \right\rangle \left| \text{🔄} \right\rangle$$

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$$\alpha \left| \text{👨🔬} \right\rangle \left| \text{👉} \right\rangle \left| \text{🔄} \right\rangle + \beta \left| \text{👨🔬} \right\rangle \left| \text{👉} \right\rangle \left| \text{🔄} \right\rangle$$



$$\alpha \left| \text{👉} \right\rangle \left| \text{👉} \right\rangle \left| \text{🔄} \right\rangle + \beta \left| \text{👨🔬} \right\rangle \left| \text{👉} \right\rangle \left| \text{🔄} \right\rangle$$



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- Preferred basis problem: how can we identify the different worlds in the wave-function?
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# It's all about information!

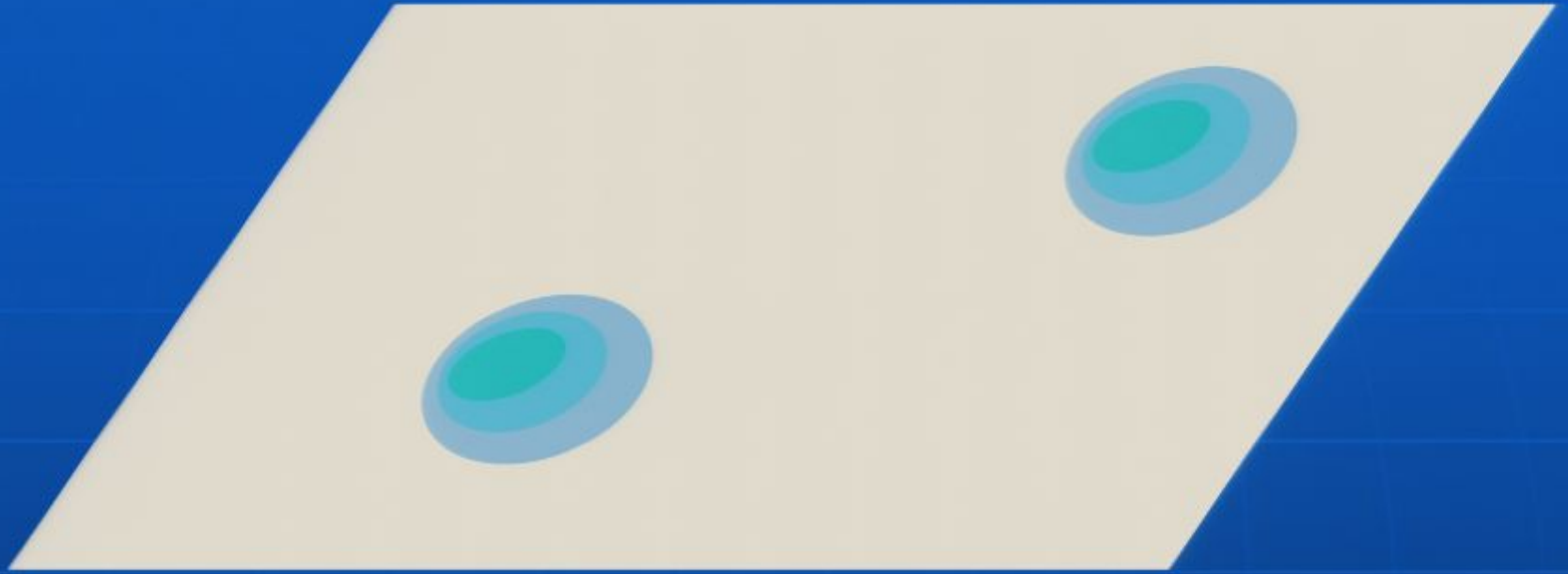
- The wave-function does not describe actual reality, but only the knowledge of an ideal observer.
- When an observer obtains information about the system he updates the quantum state.



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- When an observer obtains information about the system he updates the quantum state.

$N \times 3 \text{ D}$



Collapse



$N \times 3 \text{ D}$



$N \times 3 \text{ D}$



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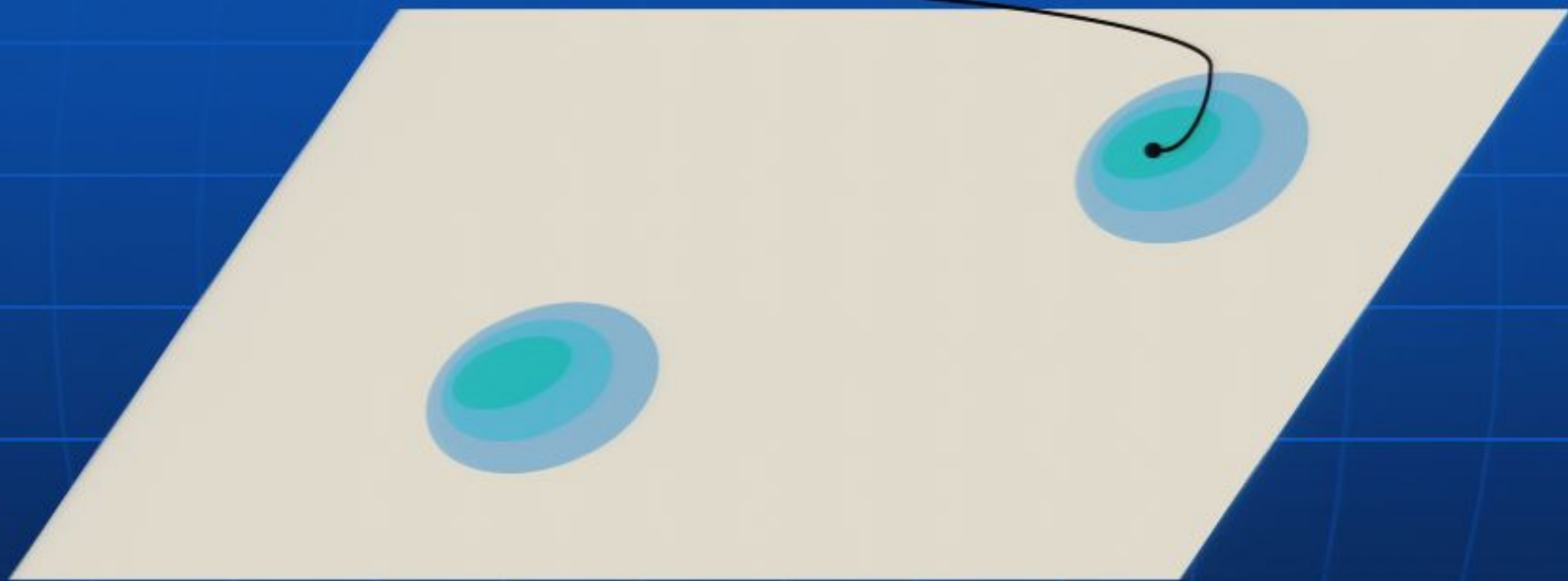
# Problems

- Knowledge about what? Knowledge about the outcome of an experiment?
- Ok, but if you are claiming to say something precise here you better specify exactly what you mean by an “an experiment”. Is it perhaps the interaction between a classical apparatus and a quantum system?
- We again run into the same problem we had with the Copenhagen interpretation.



# deBroglie-Bohm theory

$$\mathbf{X} = ((x_1, y_1, z_1), (x_2, y_2, z_2), \dots, (x_N, y_N, z_N)) \longleftrightarrow \left| \begin{array}{c} \uparrow \\ \text{V} \end{array} \right\rangle$$



A system is described by  $(\Psi(x), X(t))$ .

# Dynamics

In classical theory  $X$  evolves according to Newton's laws  $F=ma$ .

In deBroglie-Bohm theory  $X$  evolves according to the non-classical equations

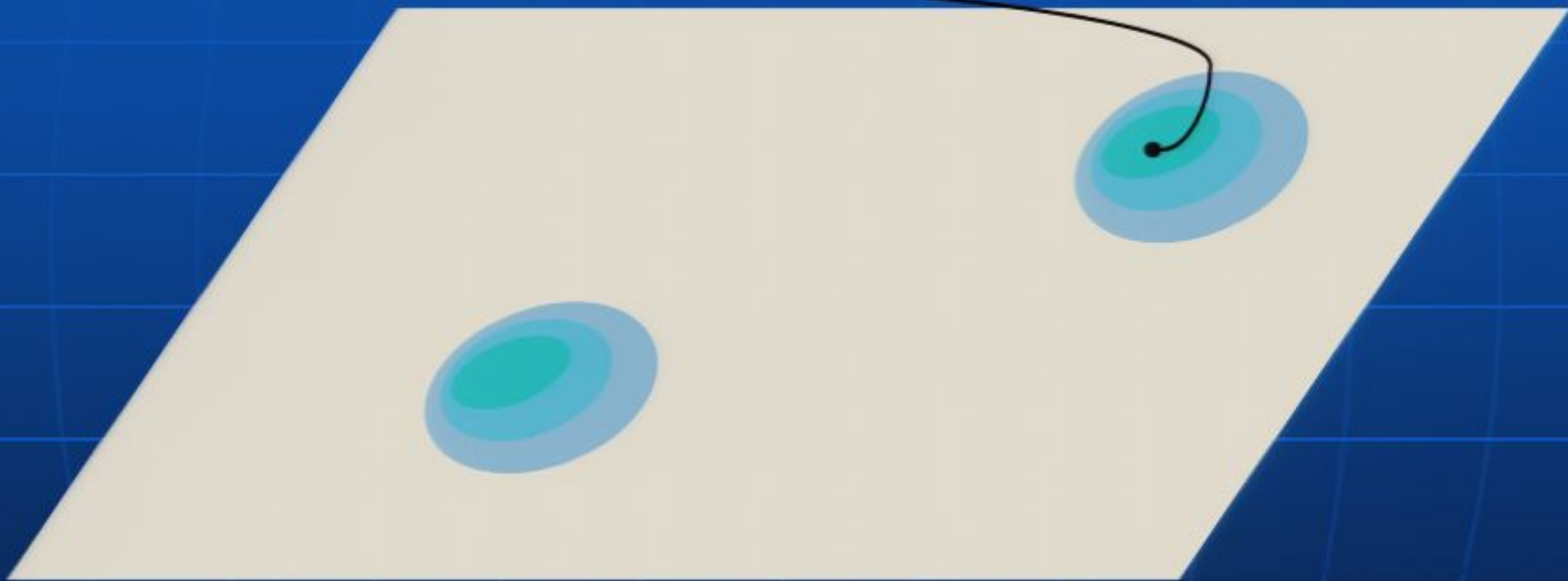
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$N \times 3 \text{ D}$



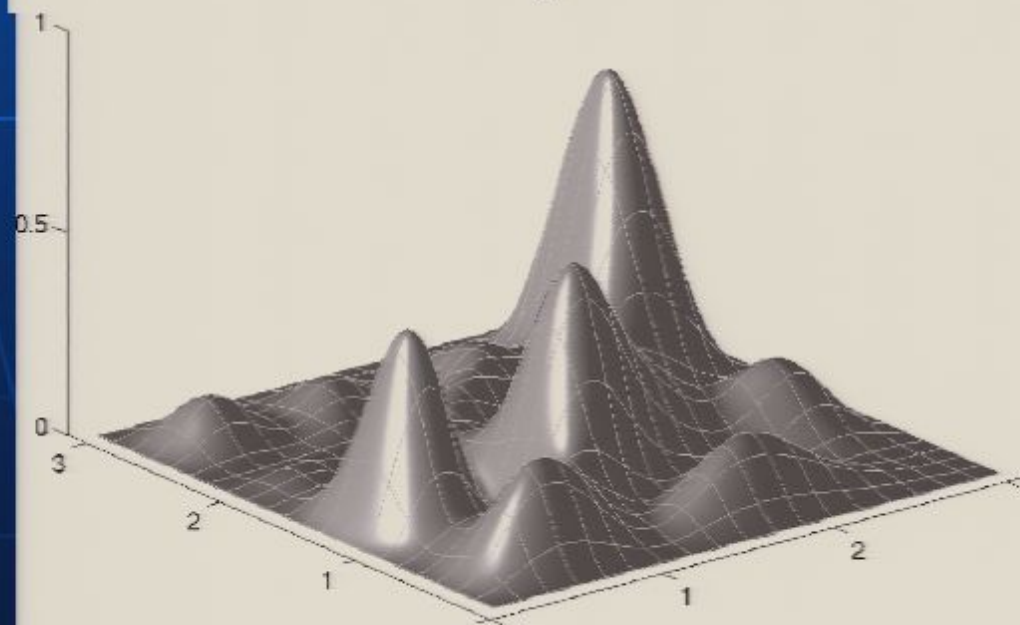
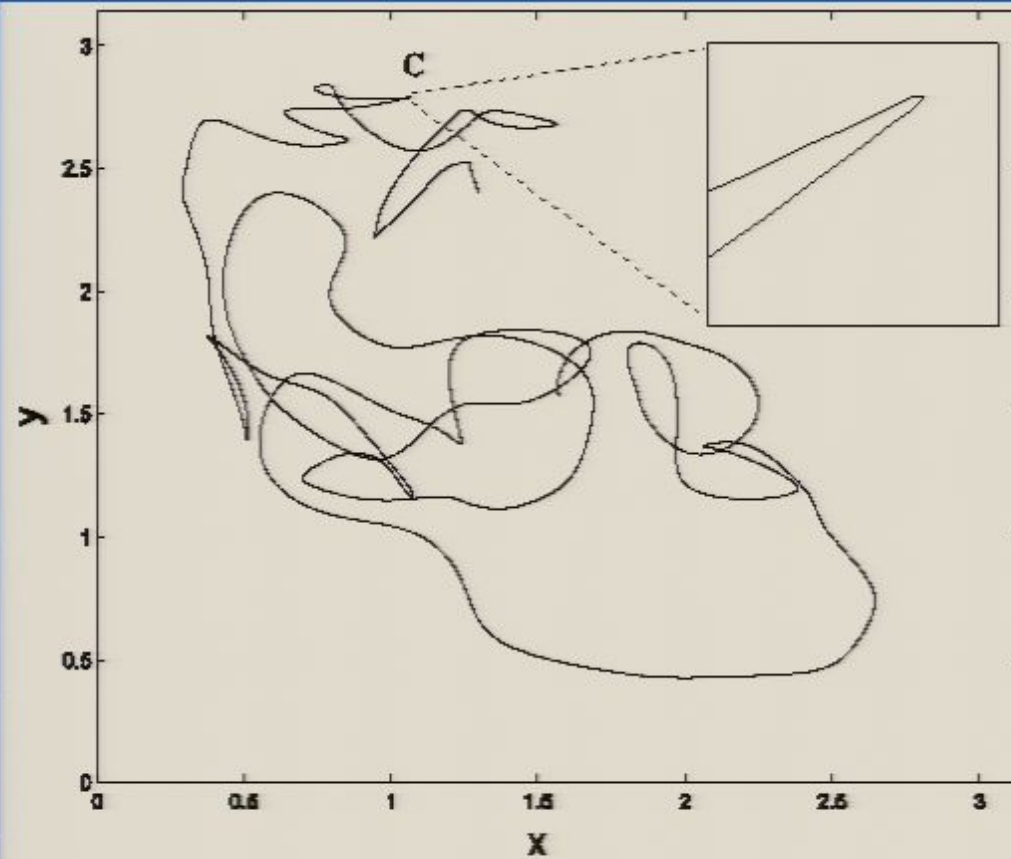
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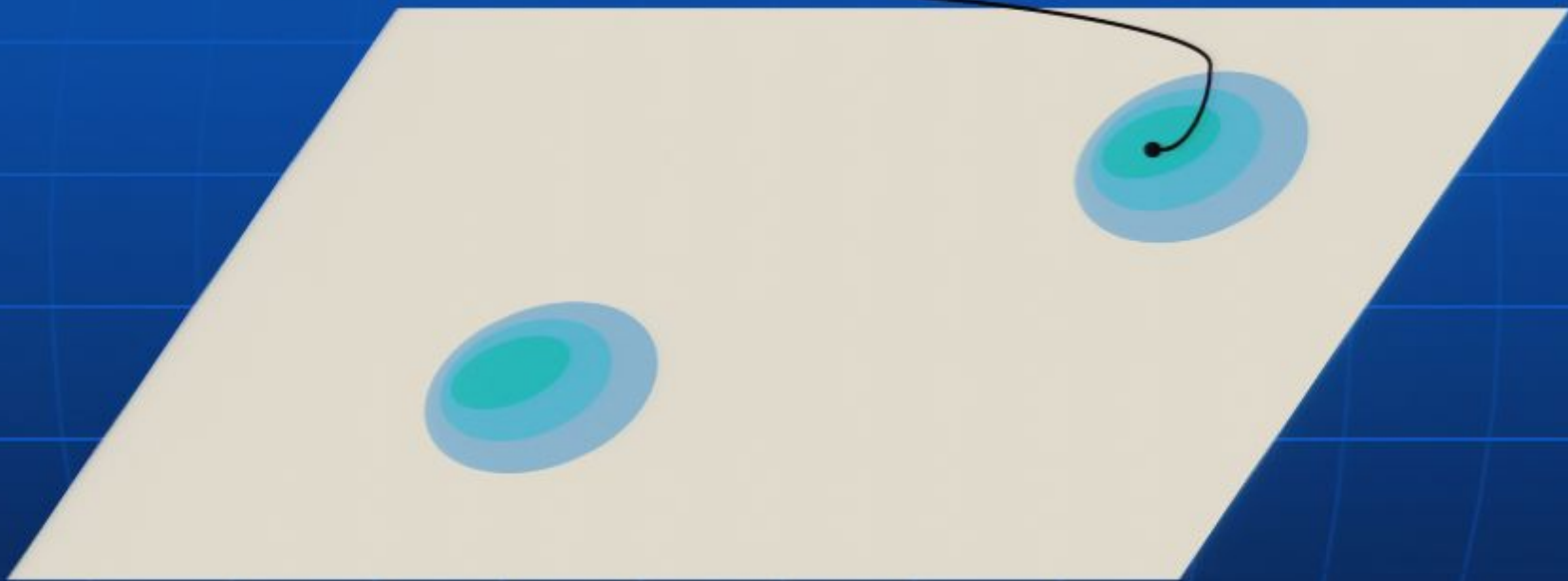
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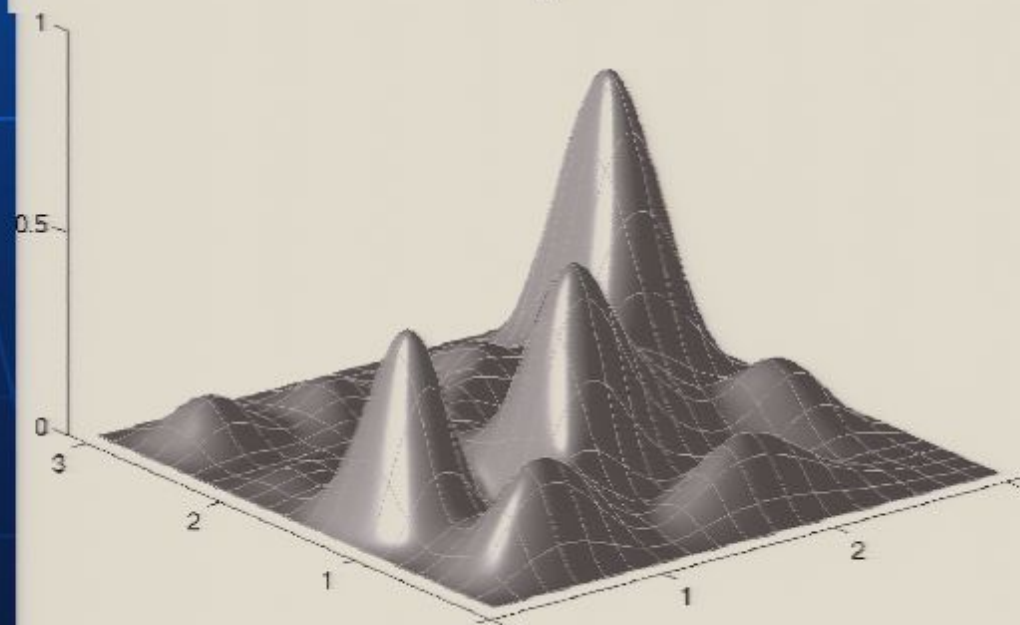
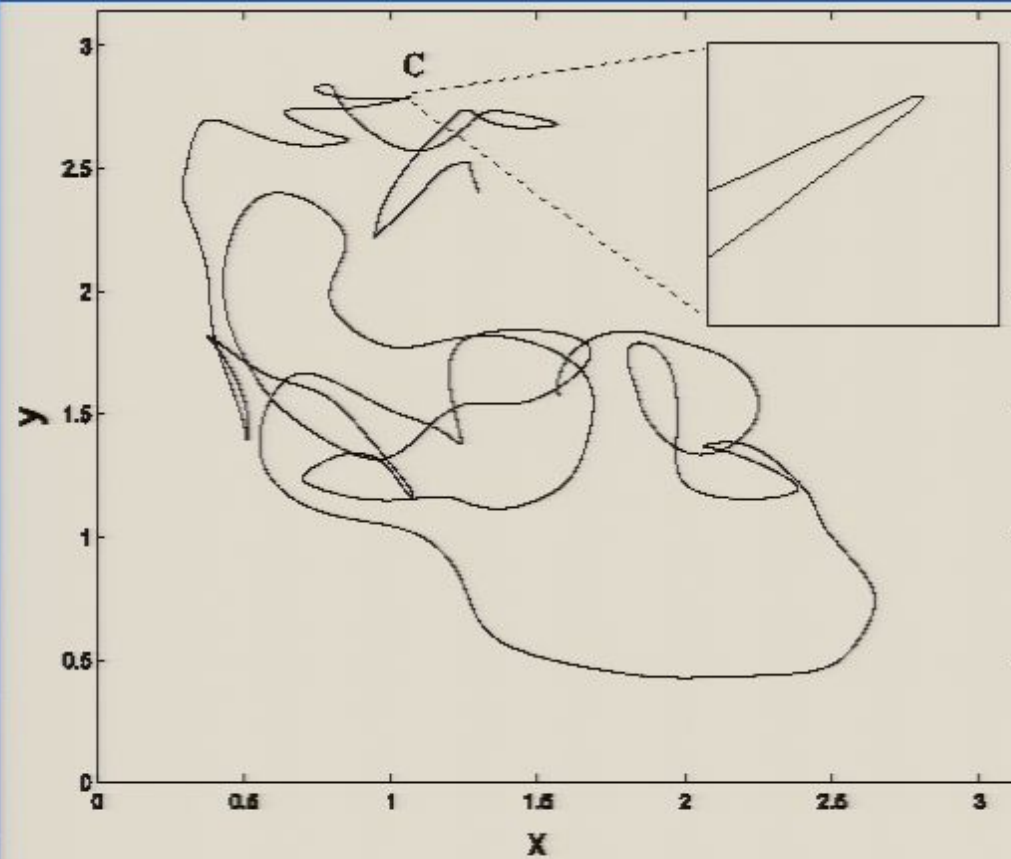
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$N \times 3 \text{ D}$



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# Good News

The theory is completely well defined, even **deterministic**, reproduces all the predictions of quantum theory (also also relativistic quantum theory) and the superposition principle is still valid.

dBB is a much richer theory with quantum theory emerging only in quantum equilibrium.

Explains the quantum statistics as a feature of quantum equilibrium.



# Problems

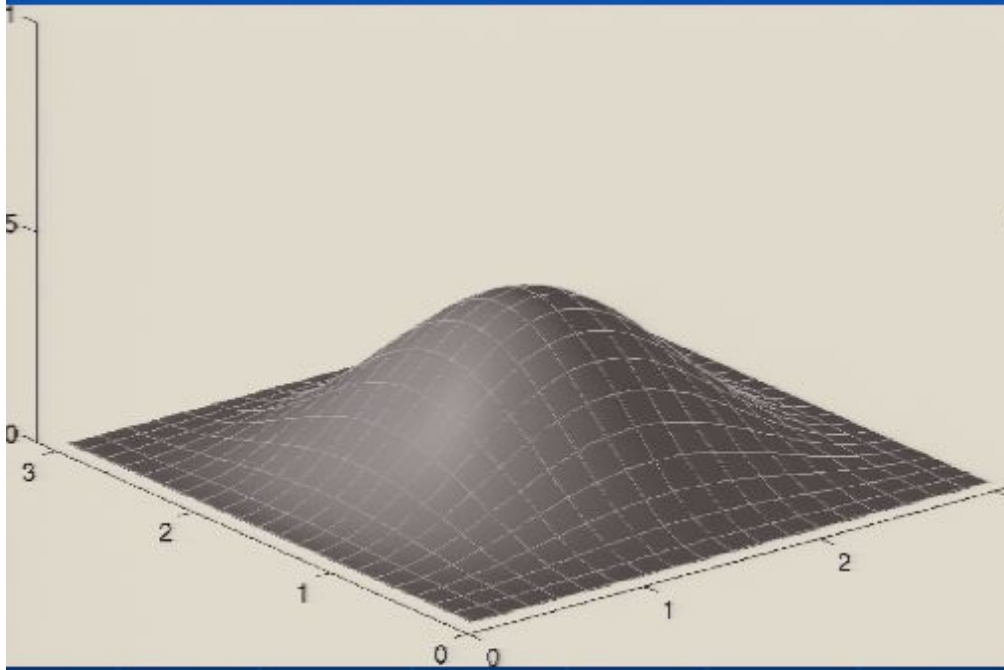
- The universe according to this theory seems rather strange. There are two things that make up the world i) the particles in 3D space ii) the wave-function that “lives” in  $3N$  D configuration space.
- The wave-function is fundamentally unobservable. The world we see is represented by the configuration  $X(t)$  just as in Newtonian physics.
- Empty wave problem.



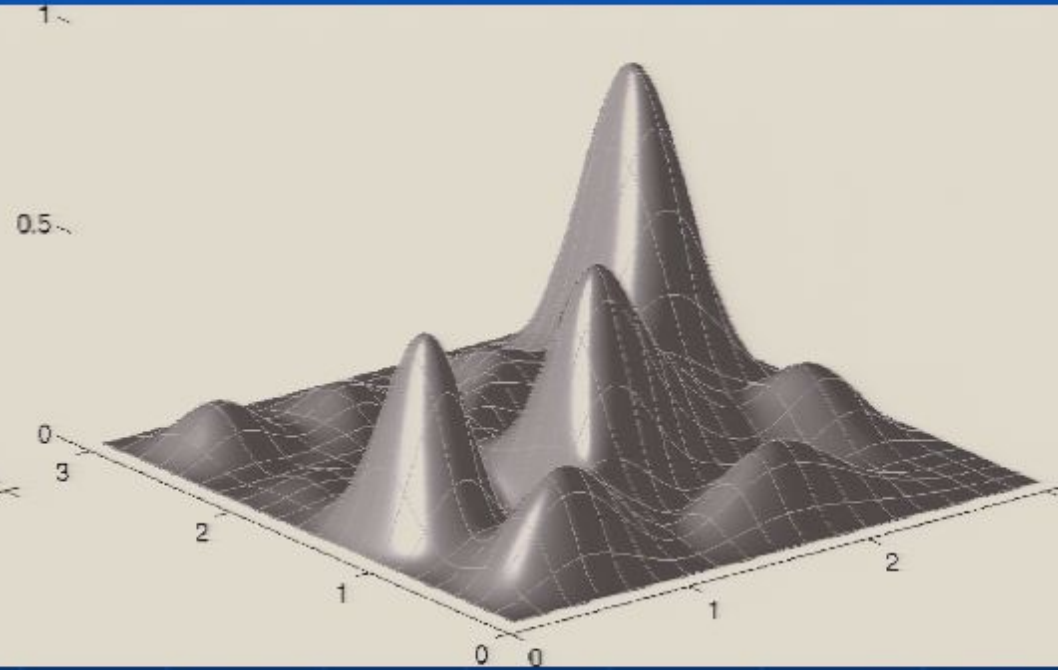
# Conclusion

- Quantum theory is an extremely successful theory. Yet it is hard to see how it really can be a fundamental theory.
- Out of the interpretations only the collapse theories and hidden variable theories are precisely formulated without vague concepts like 'classical', microscopic.
- But both of these are different theories with different predictions than quantum theory.

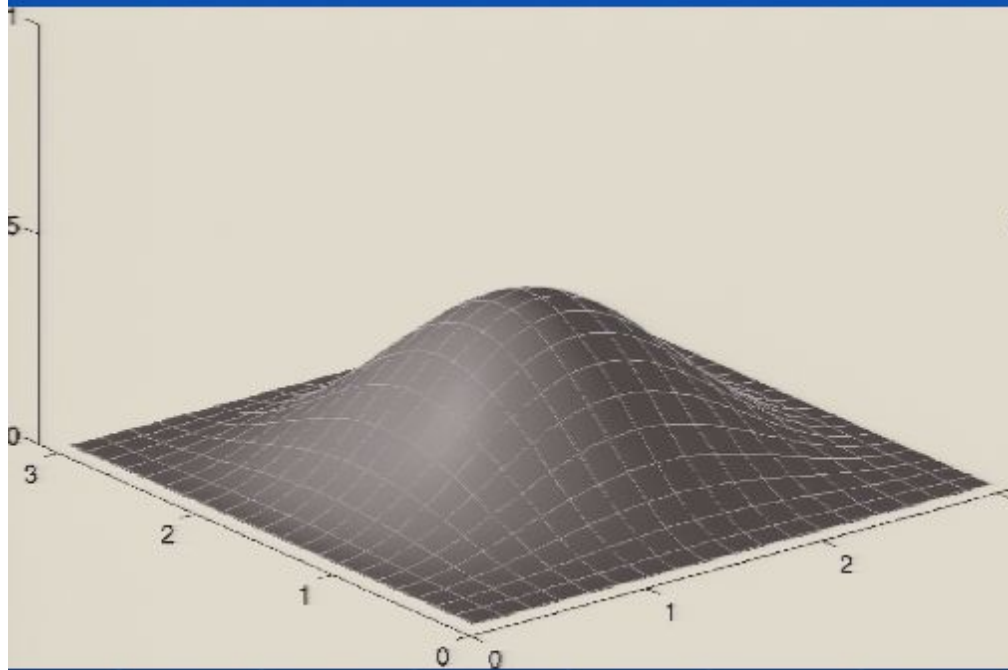
$P(x,y)$  at  $t=0$



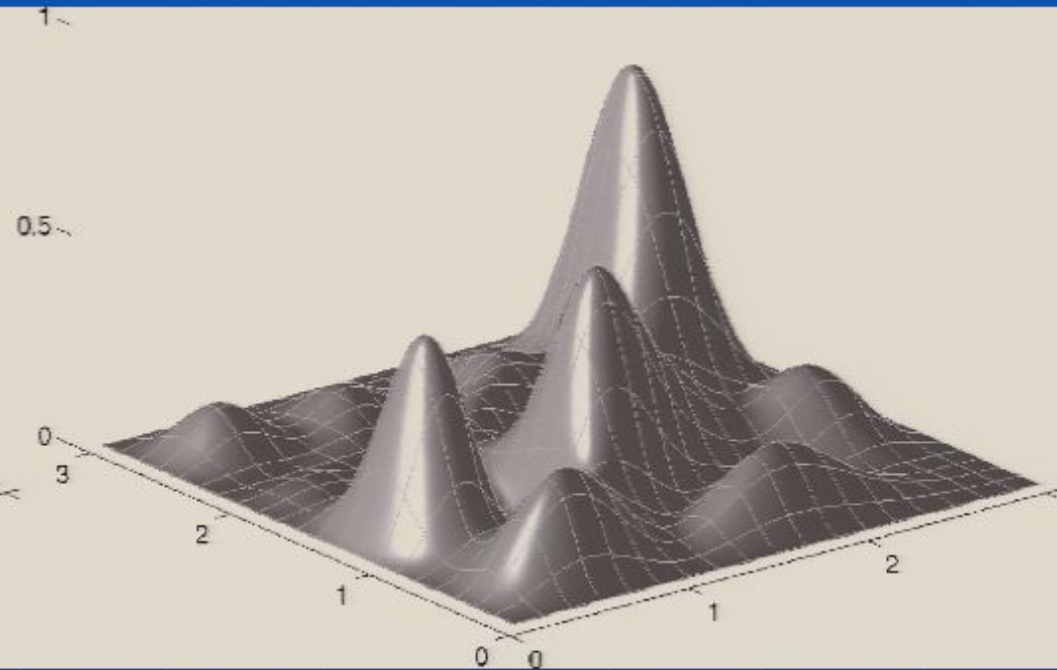
$|\psi(x,y)|^2$  at  $t=0$



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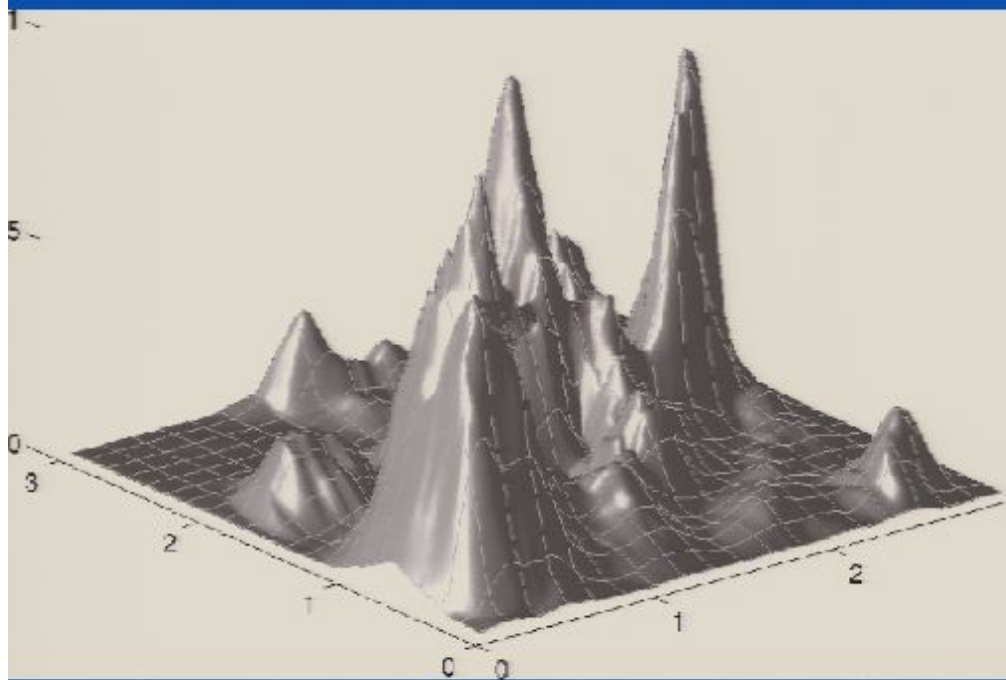


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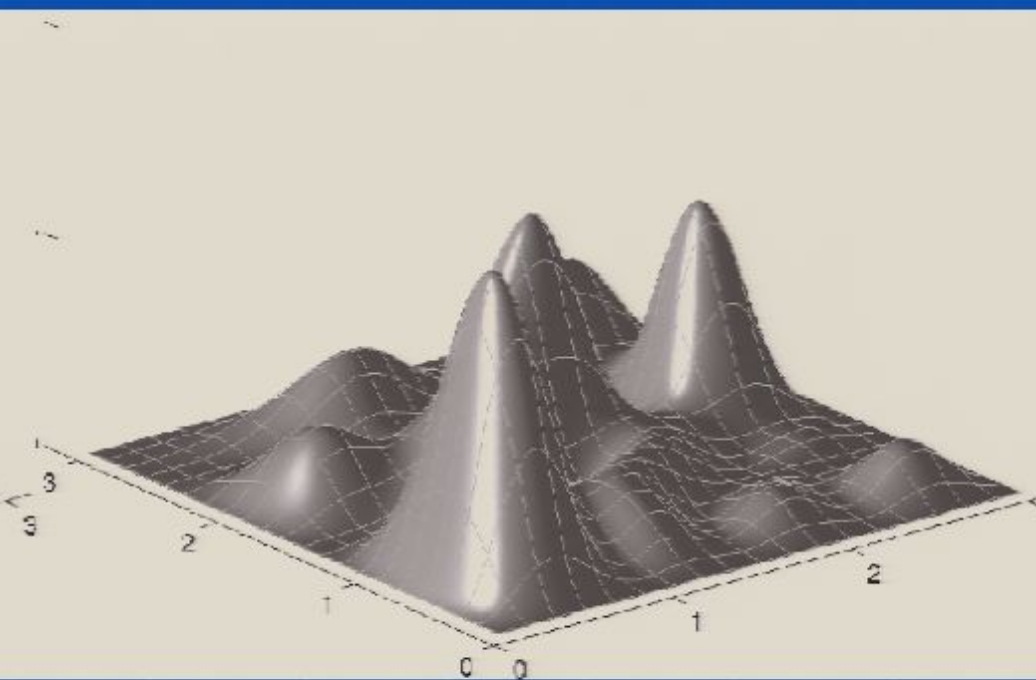




$P(x,y)$  at  $t=2\pi$

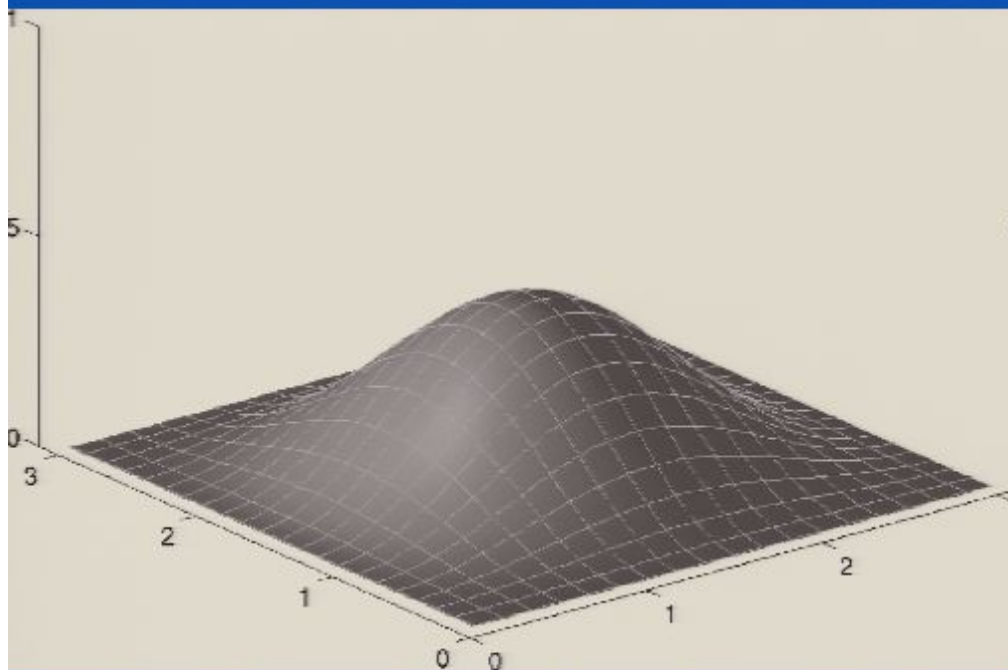


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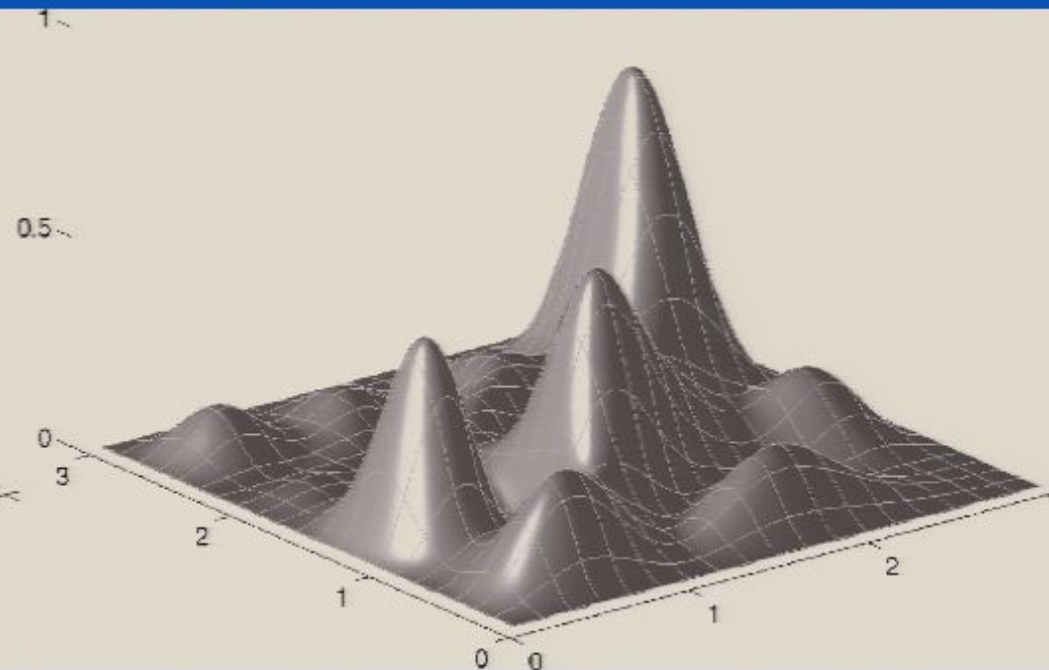




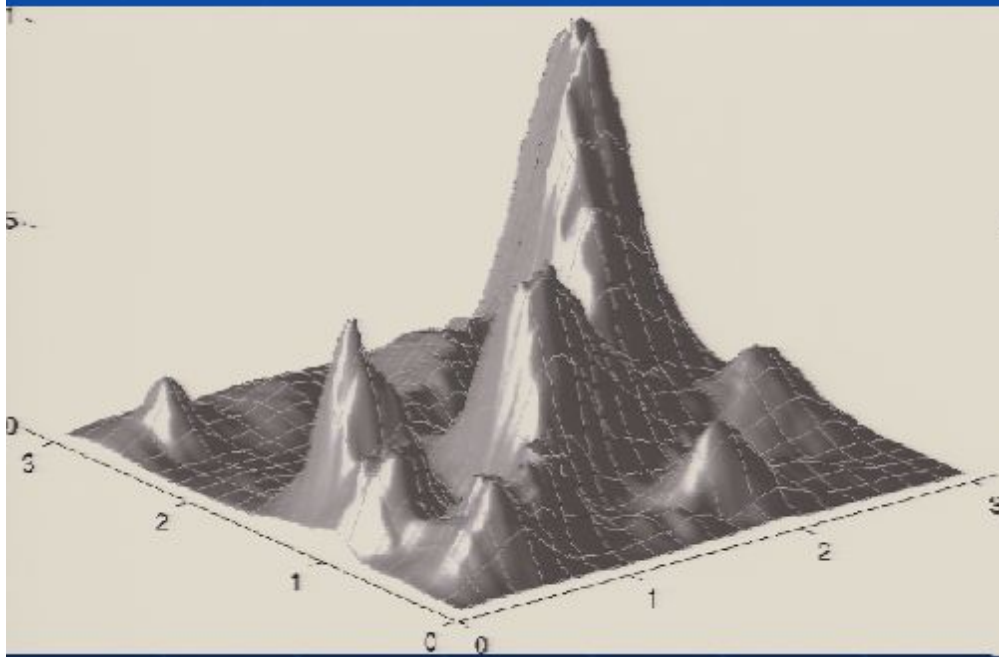
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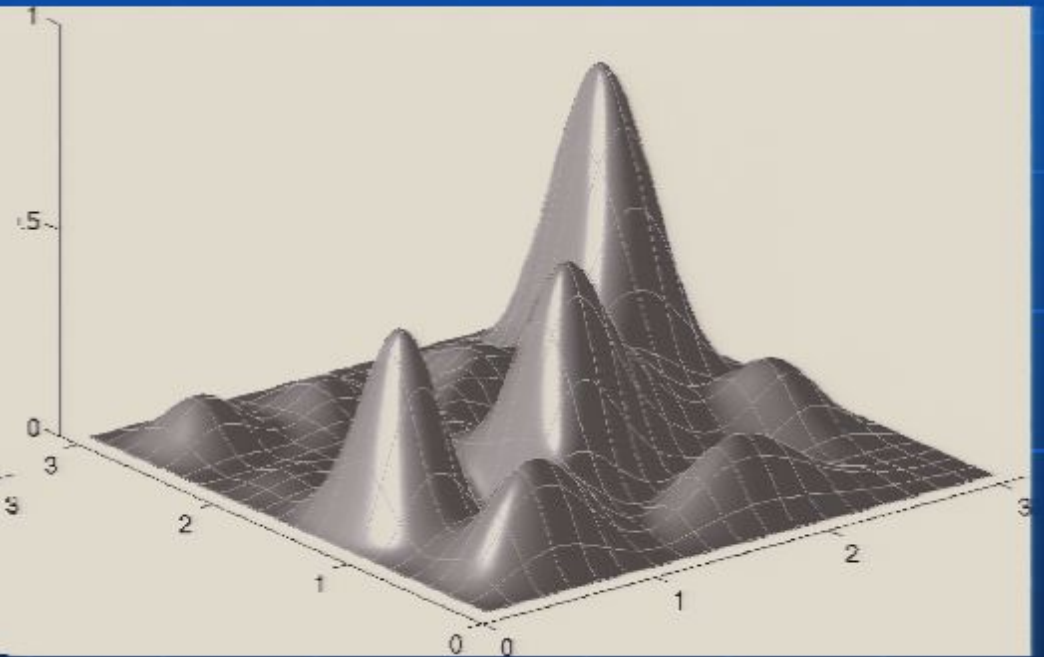
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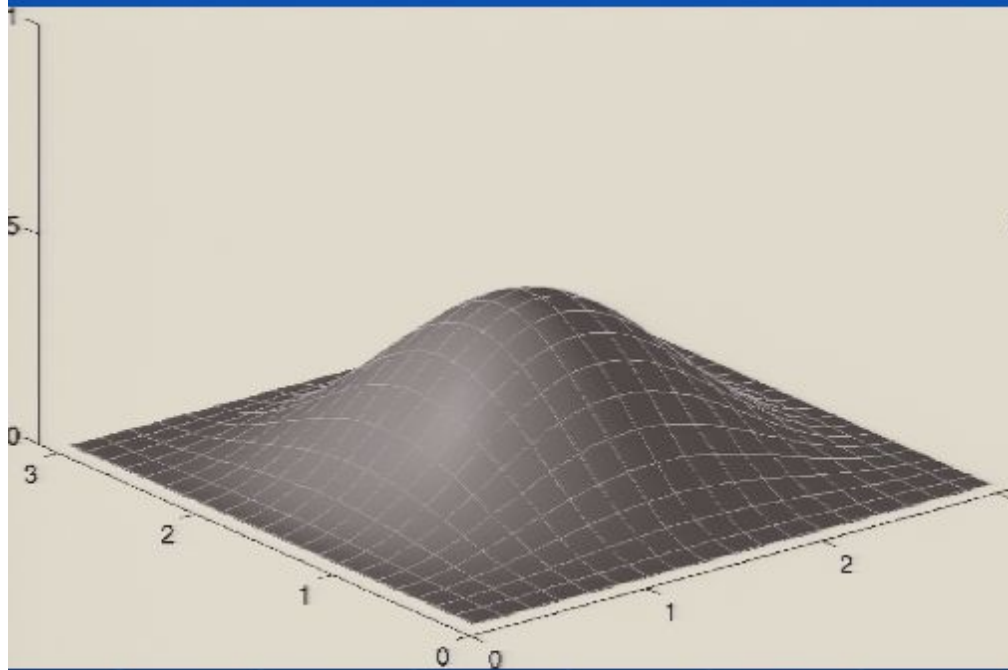
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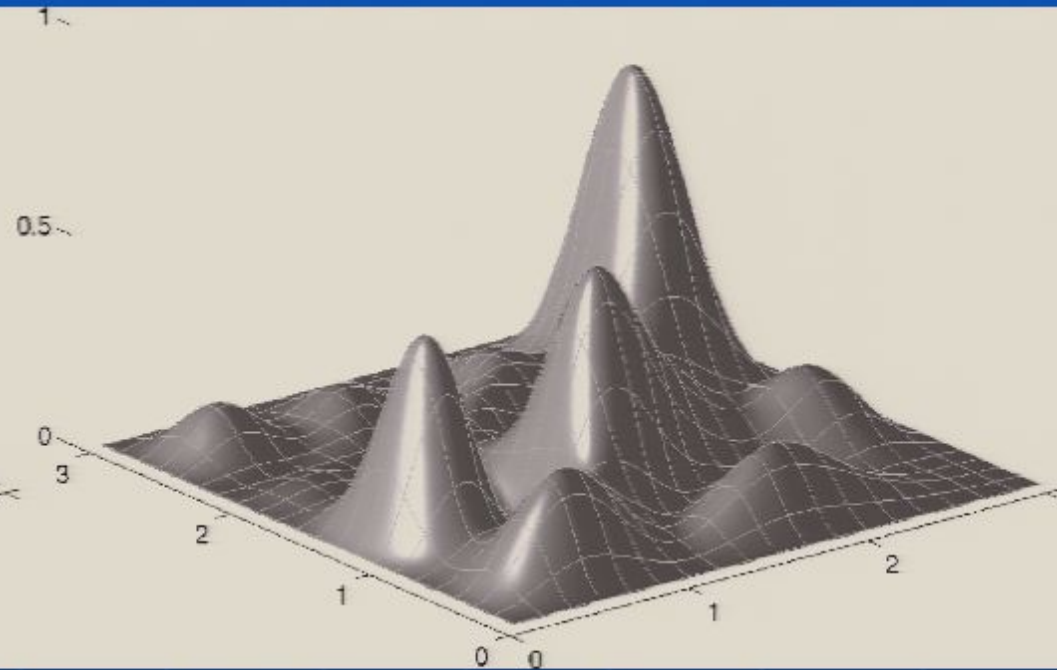
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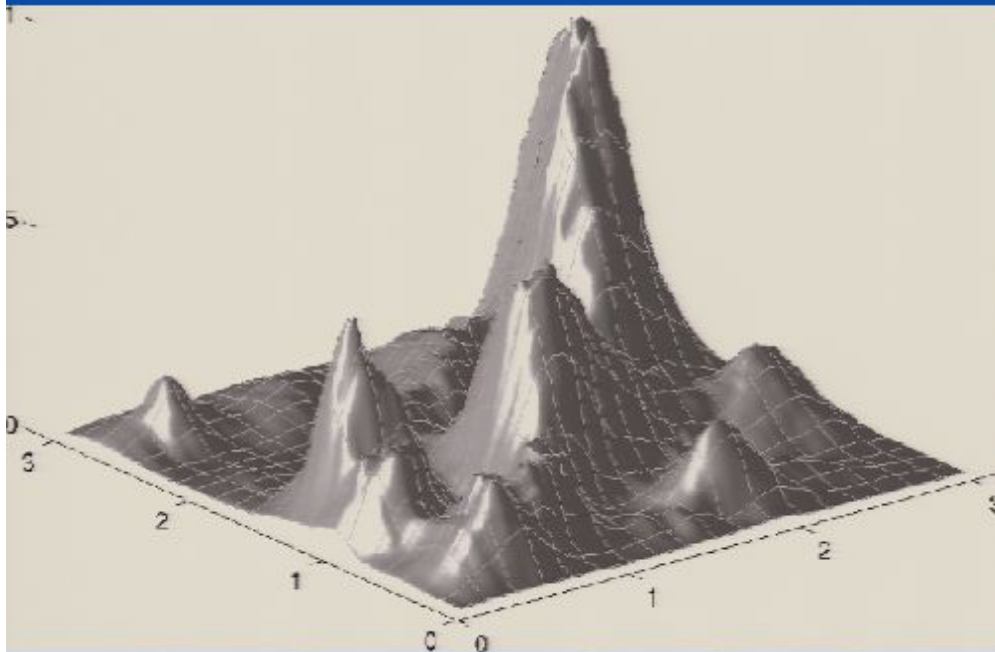
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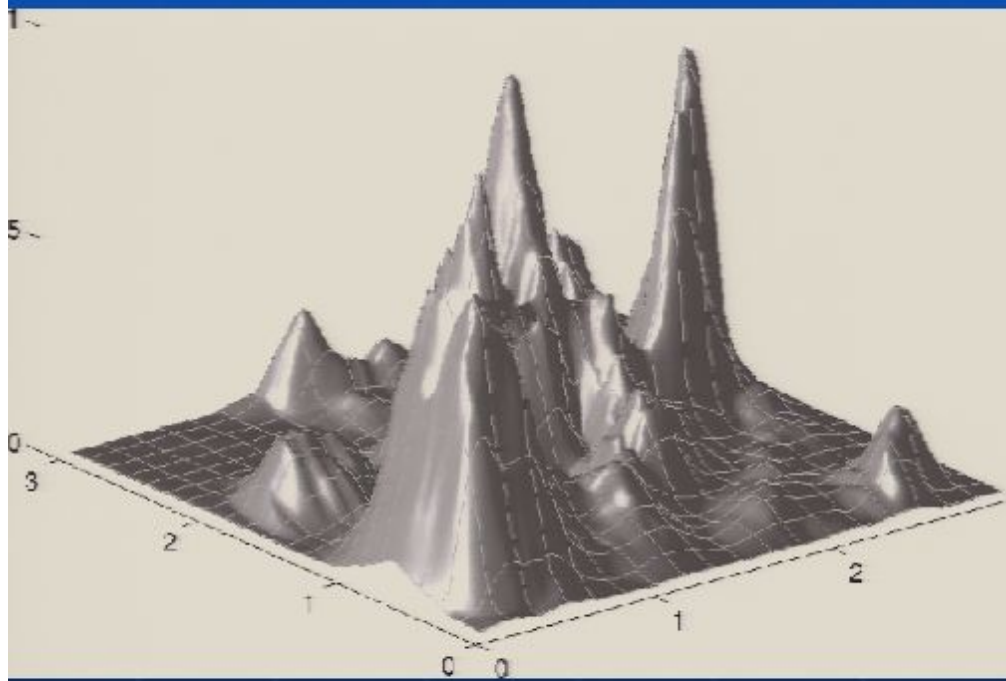
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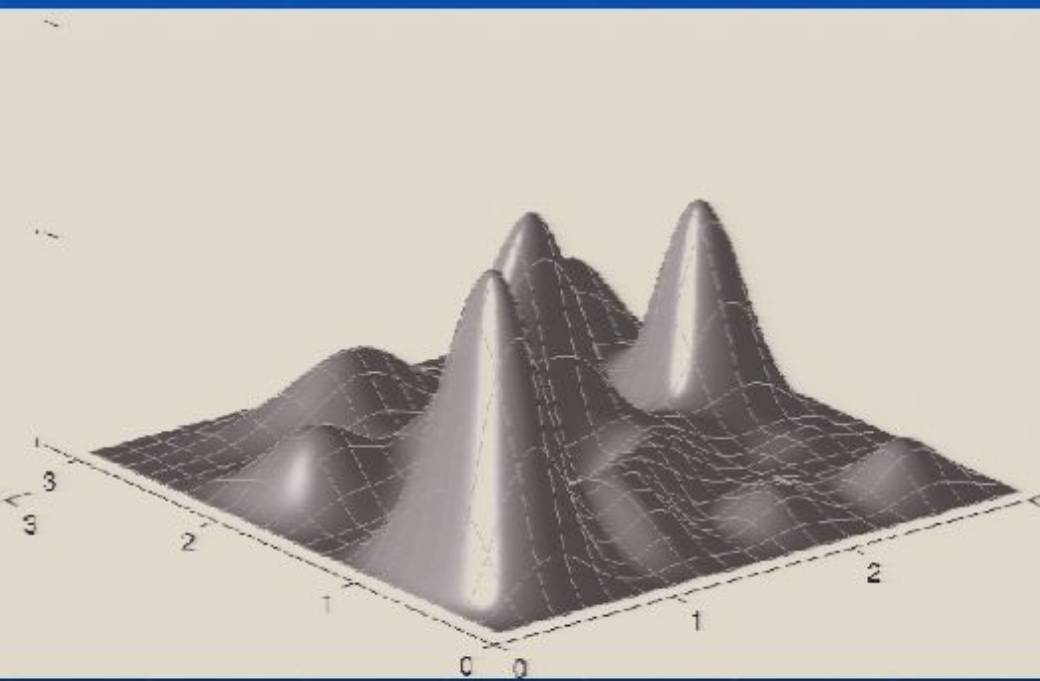
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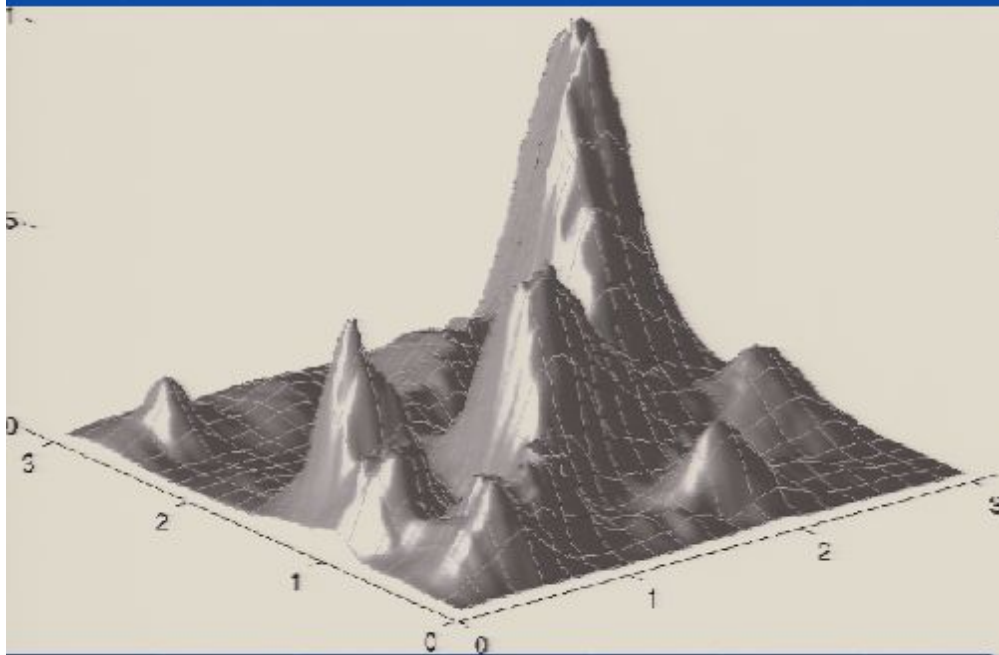
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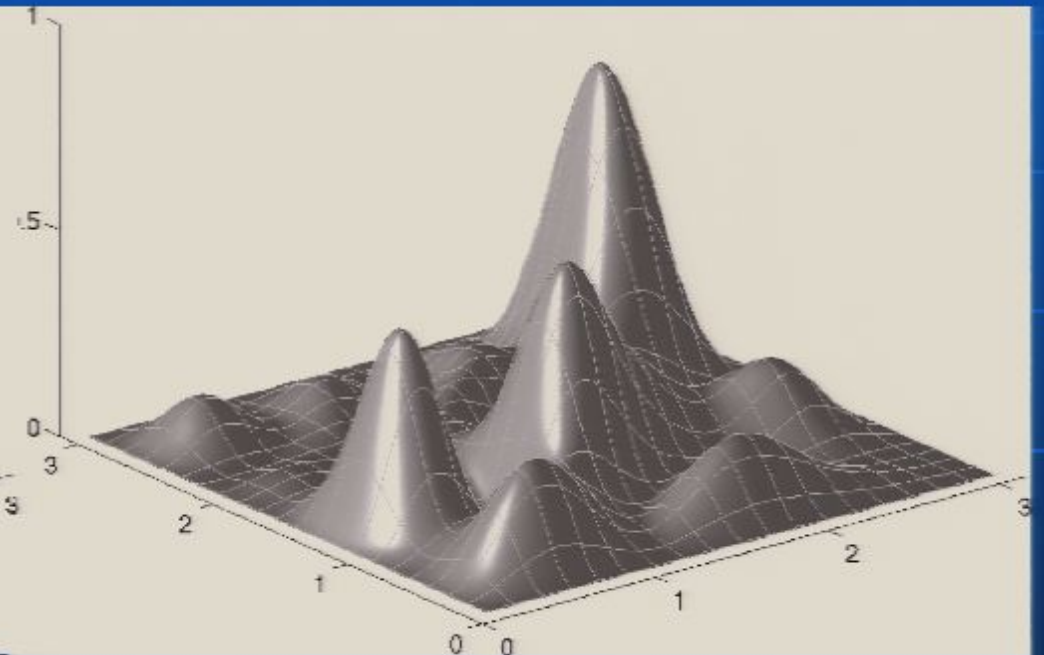
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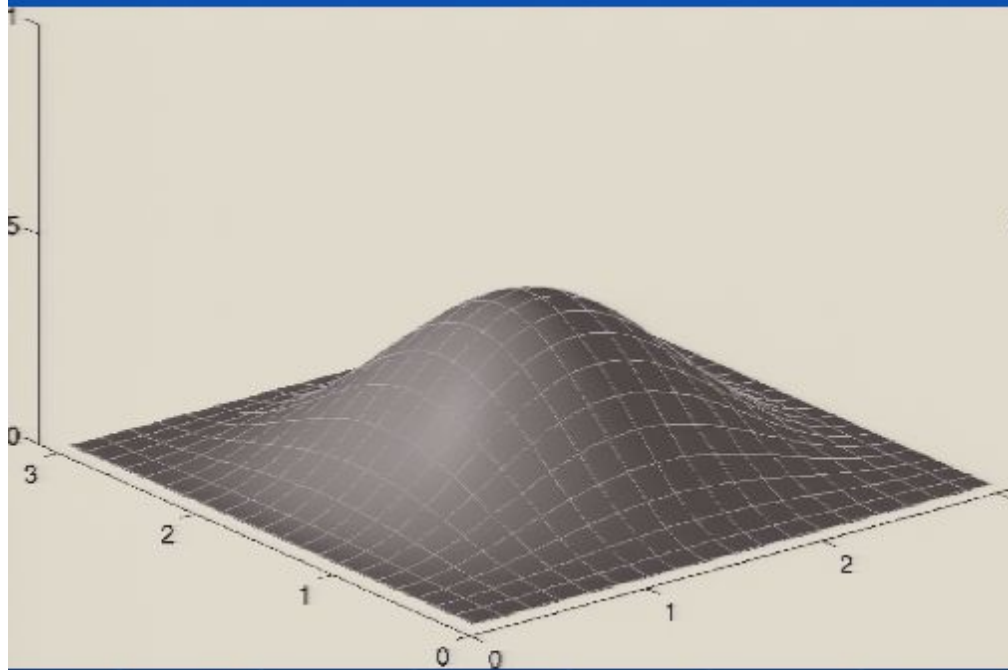
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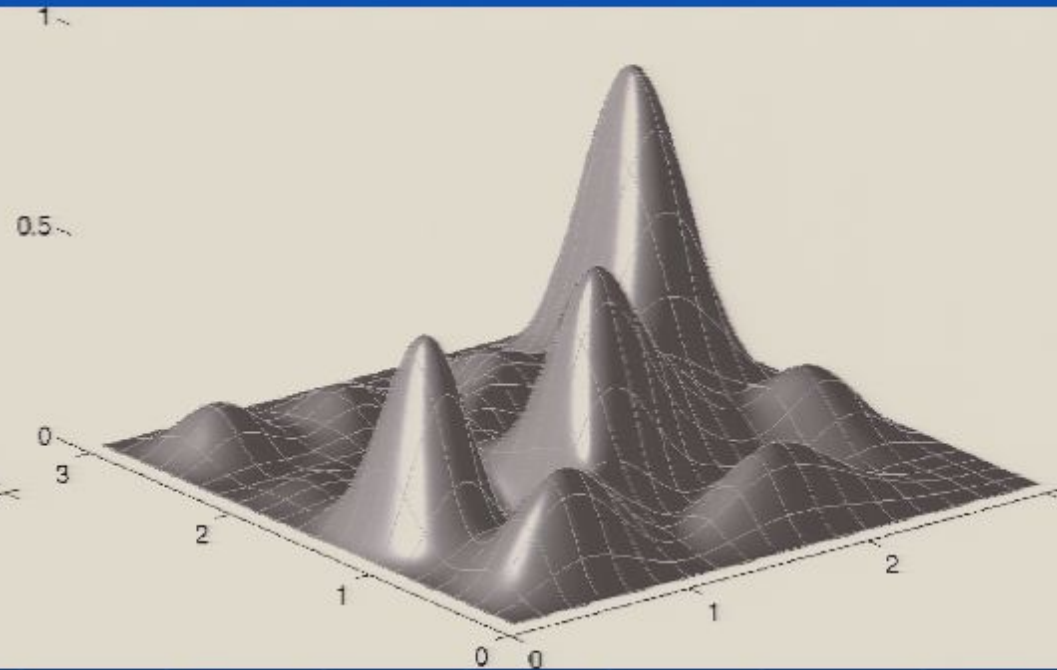
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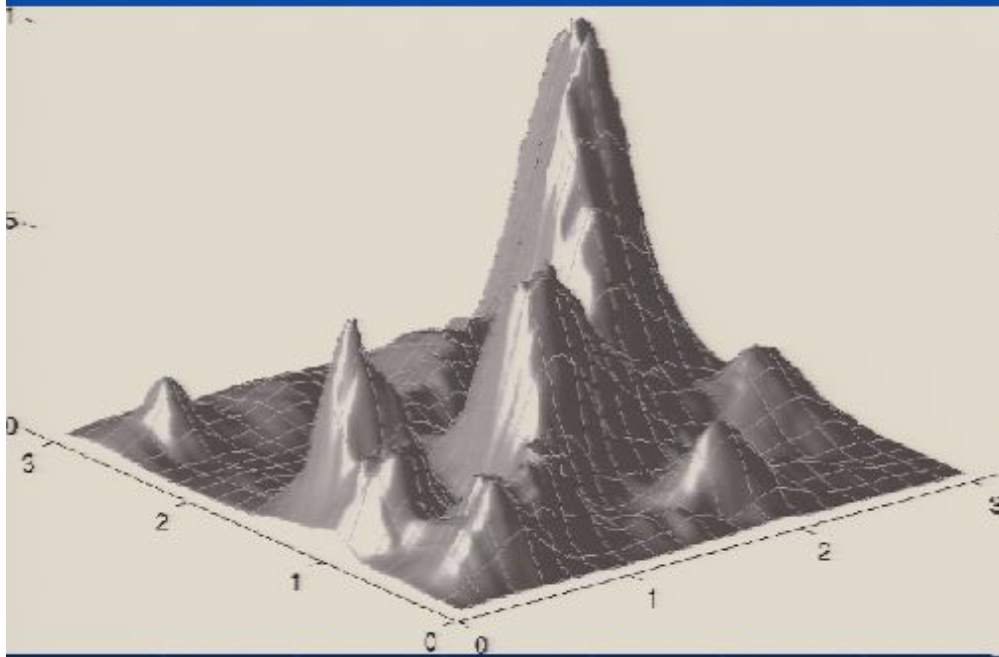
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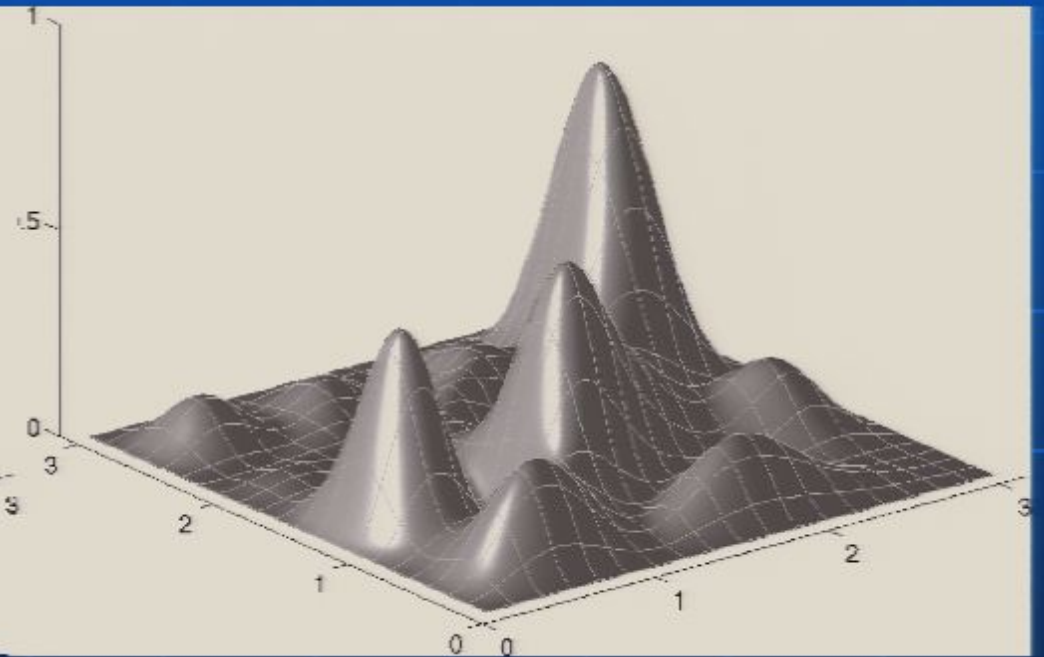
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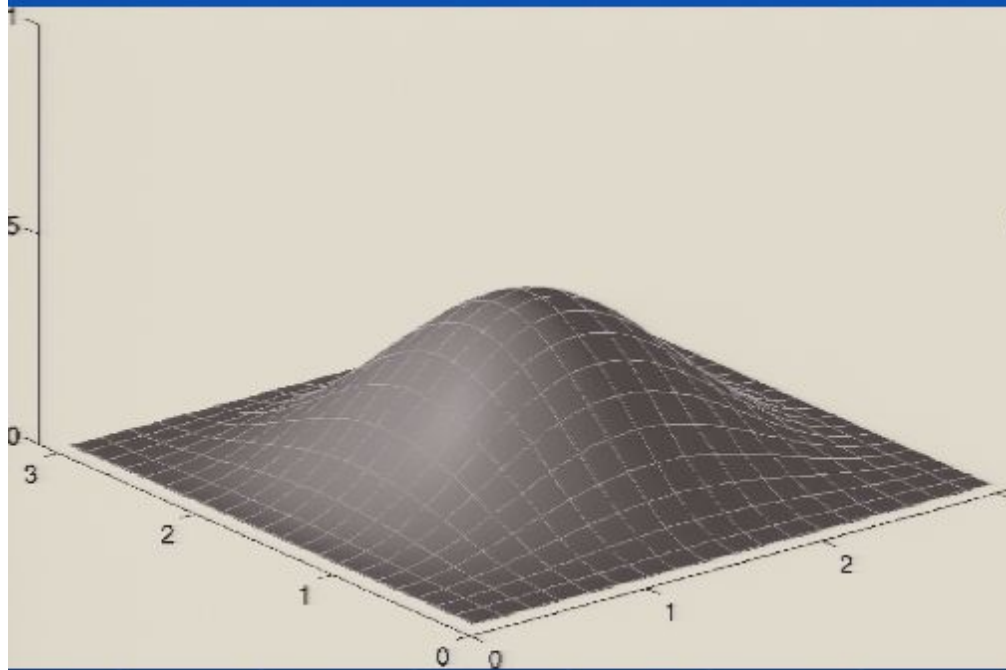


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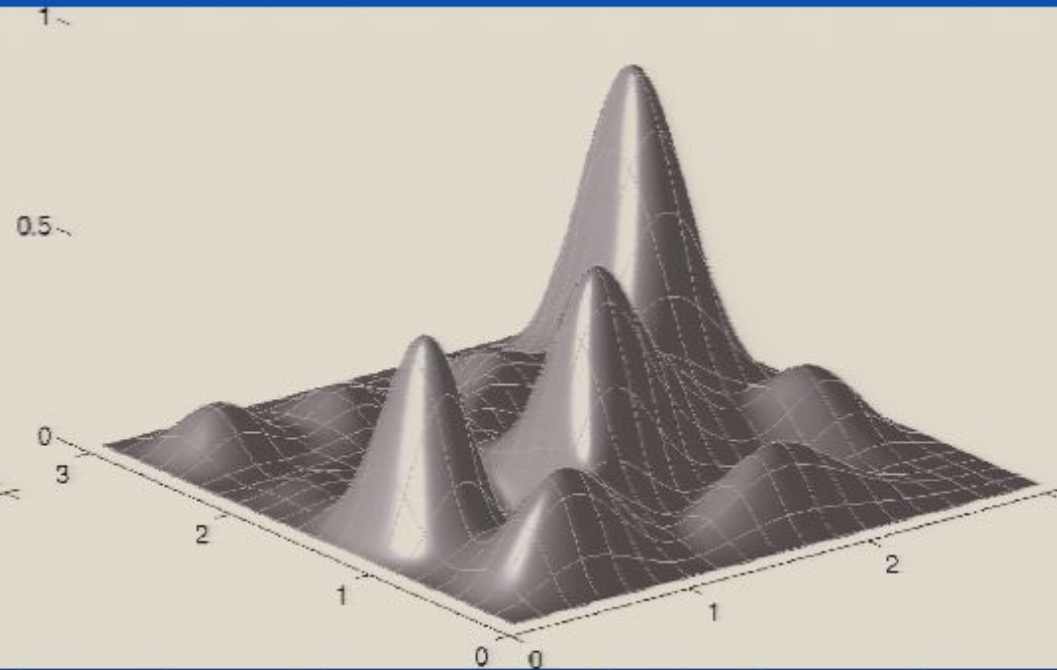




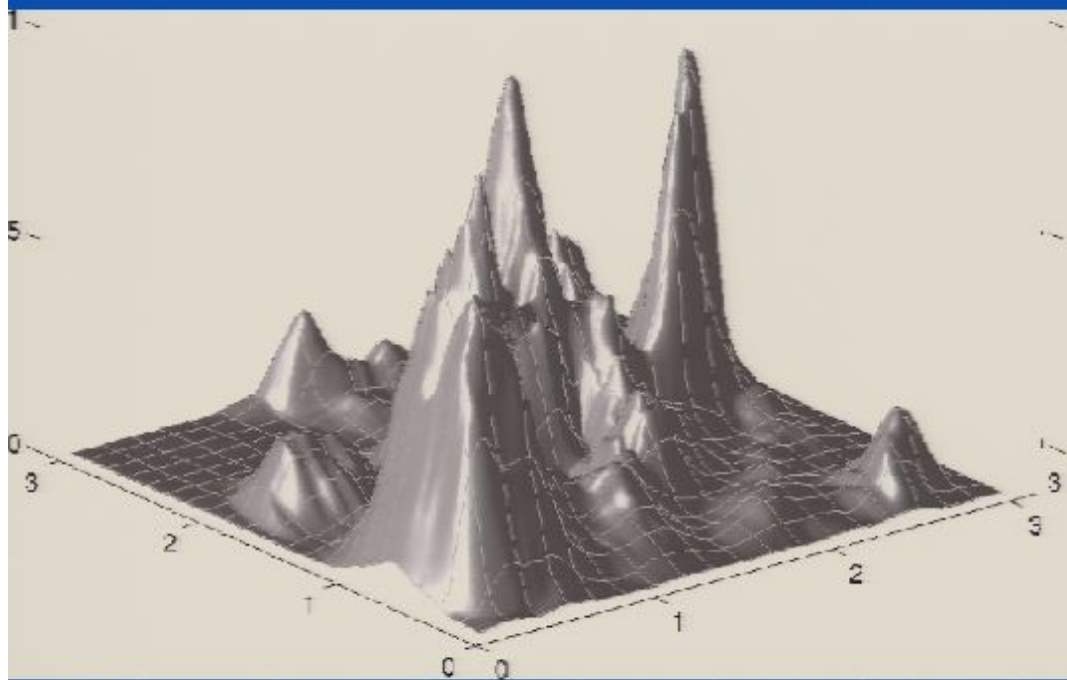
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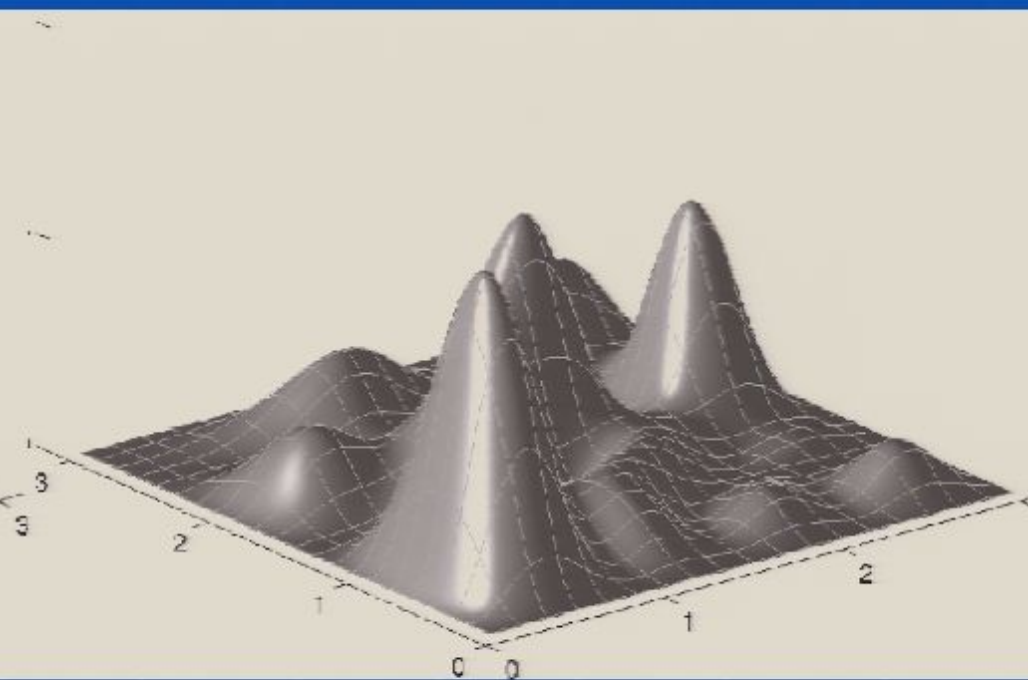
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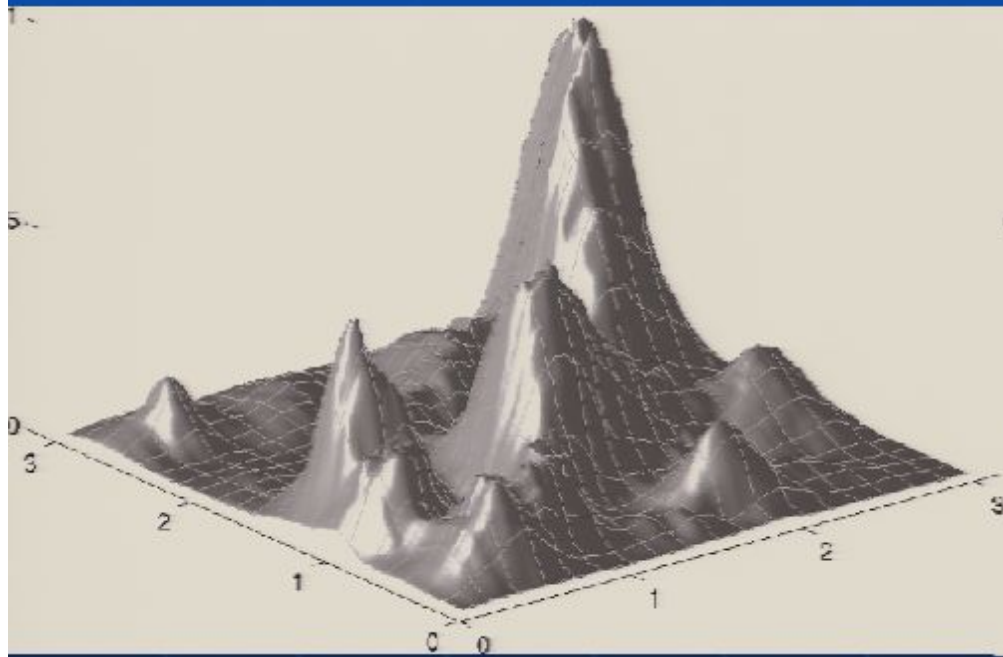
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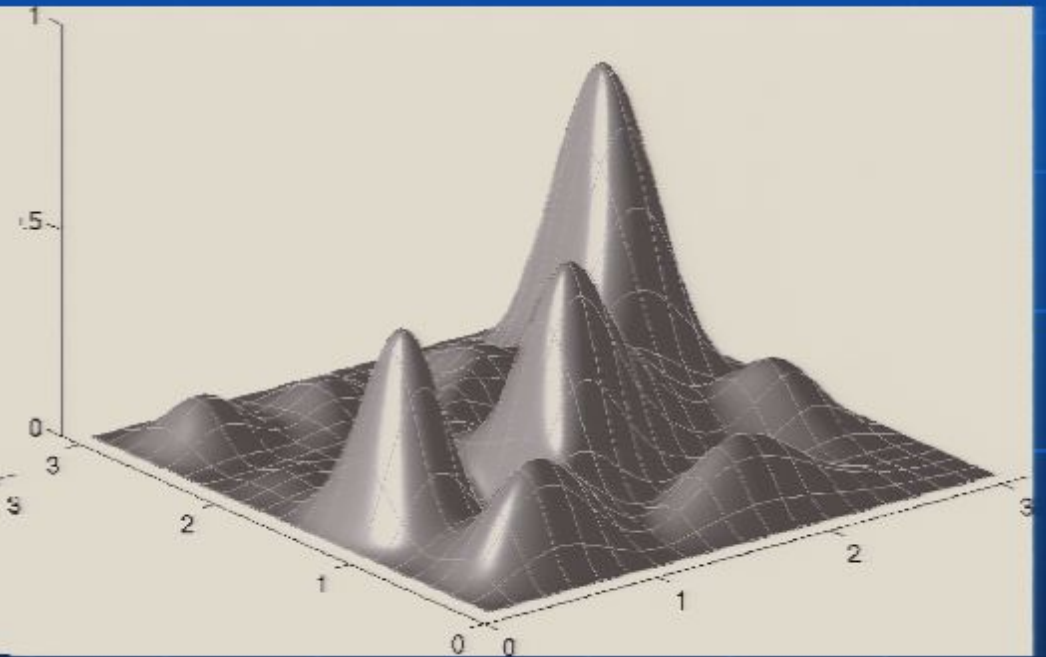
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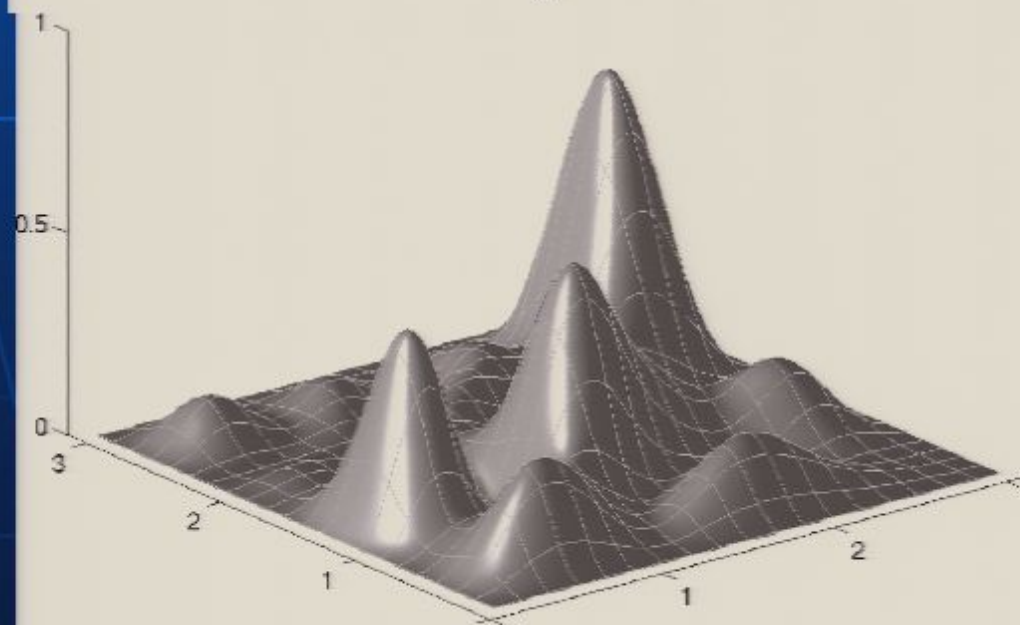
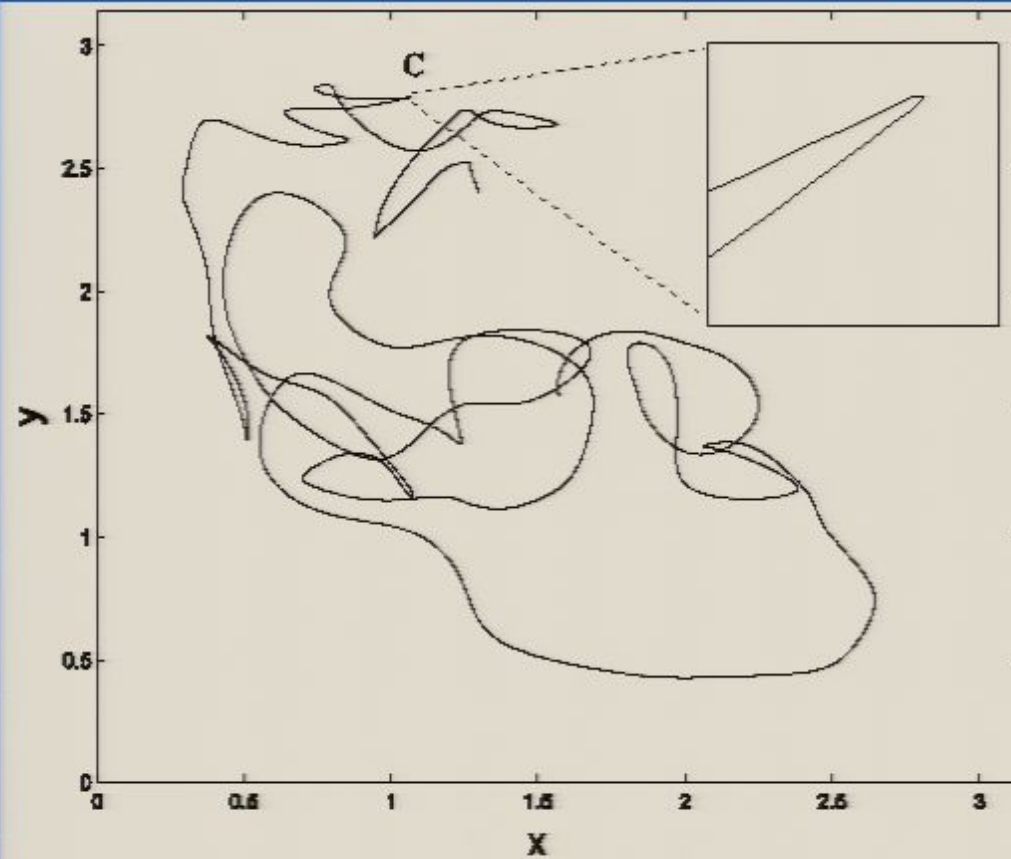


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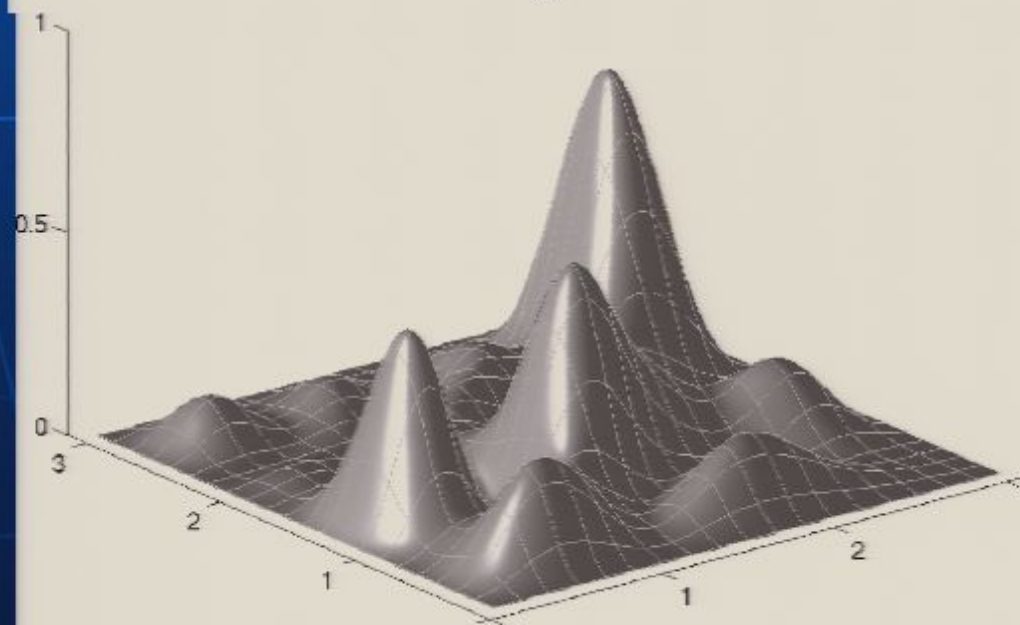
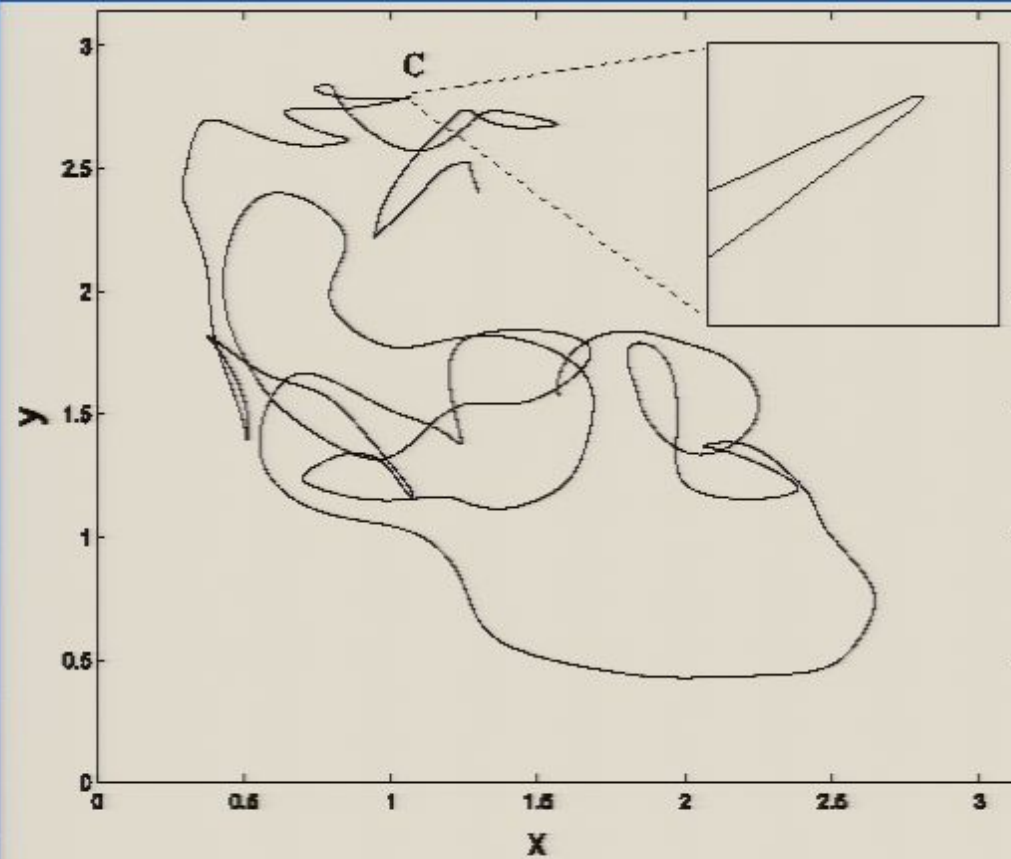


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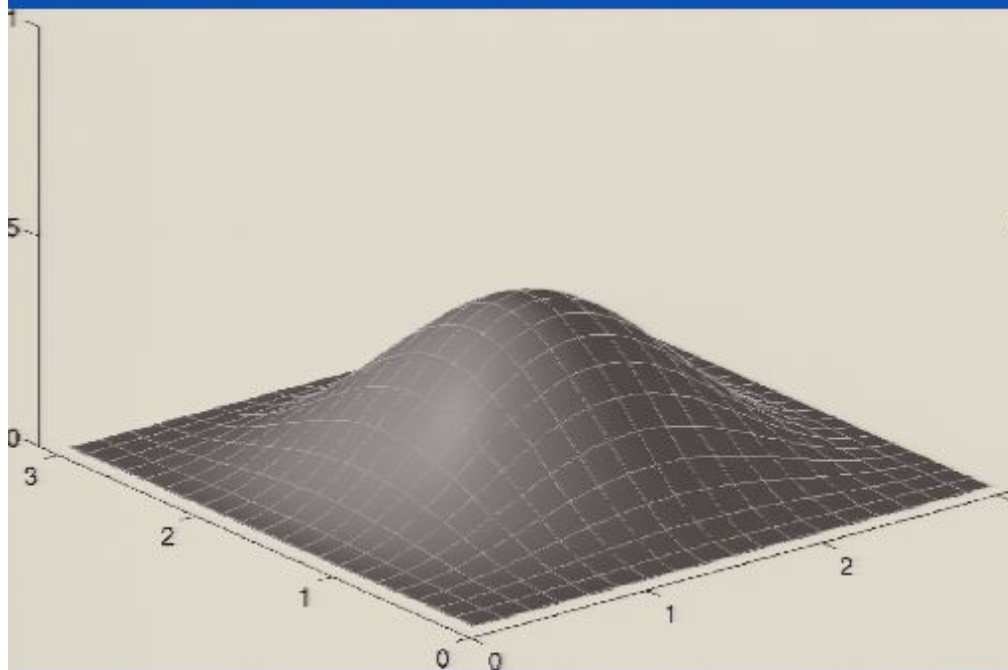
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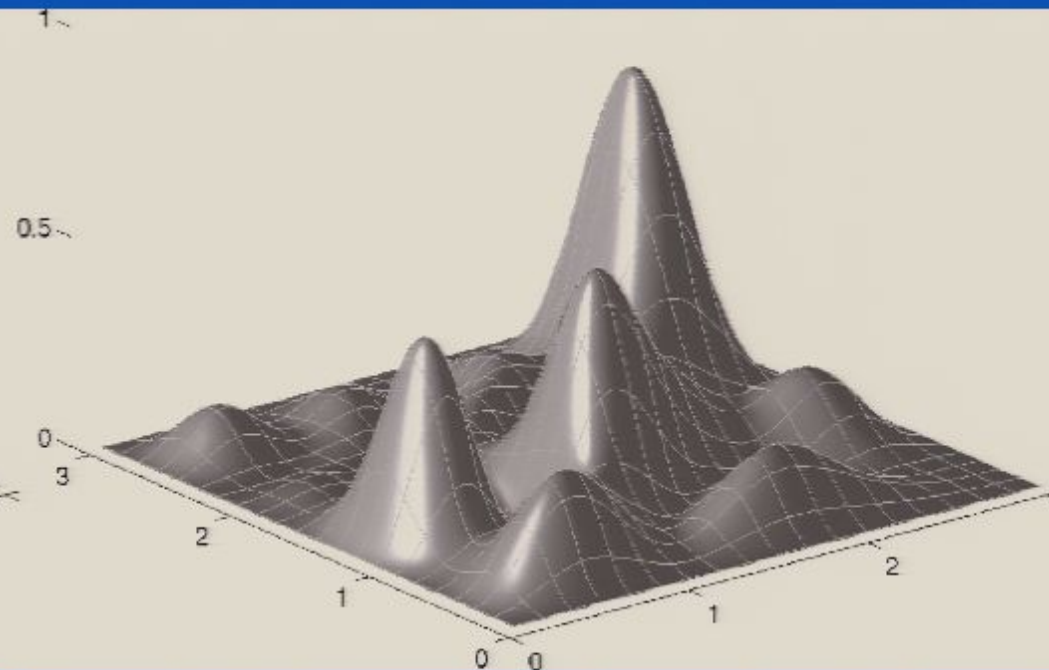
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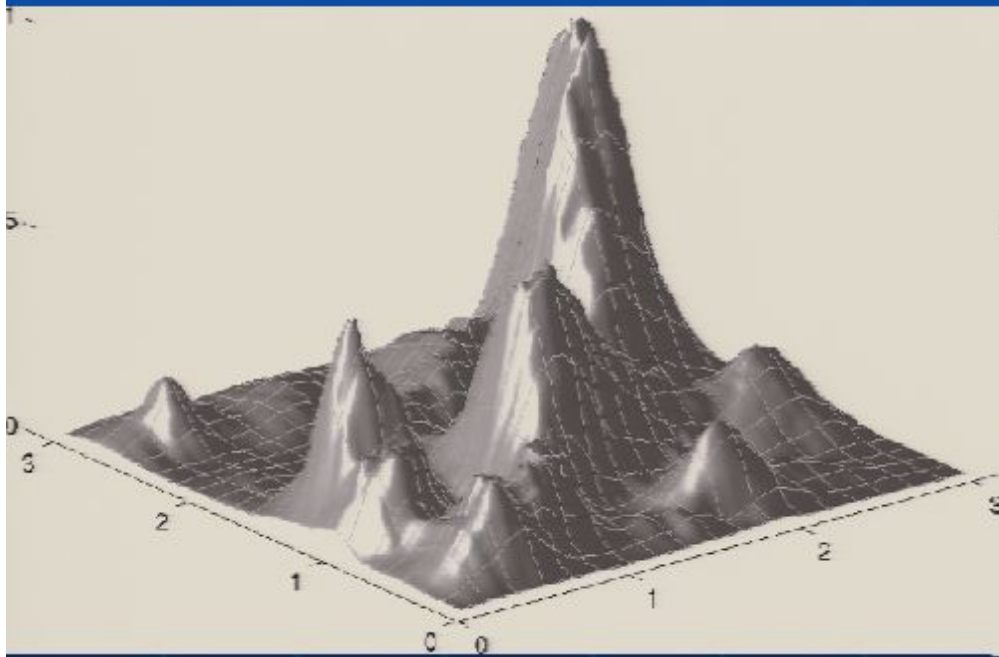


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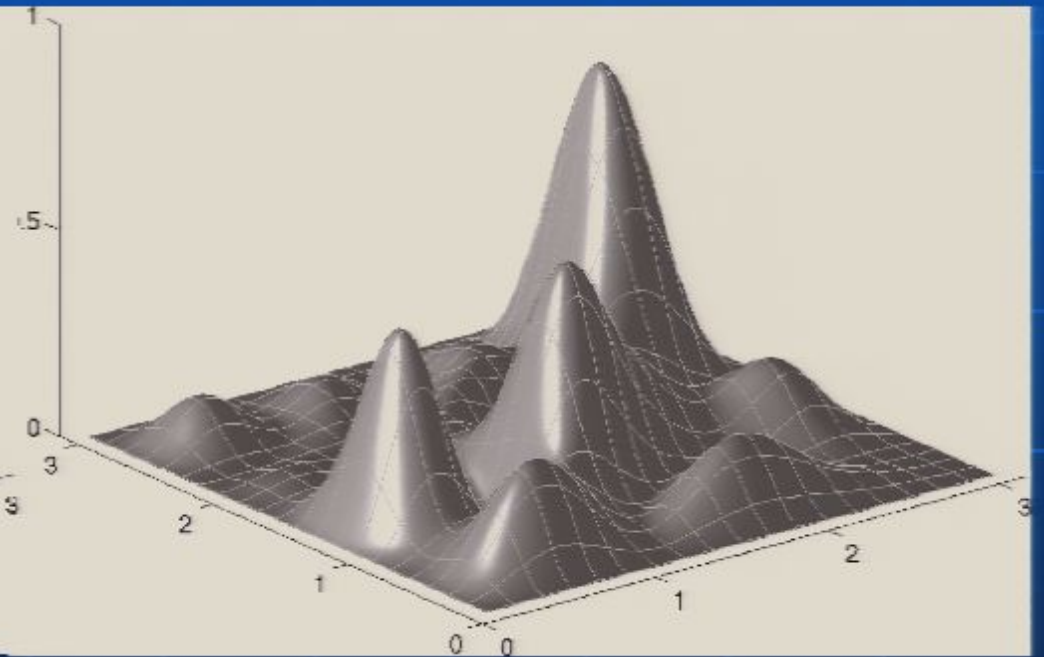




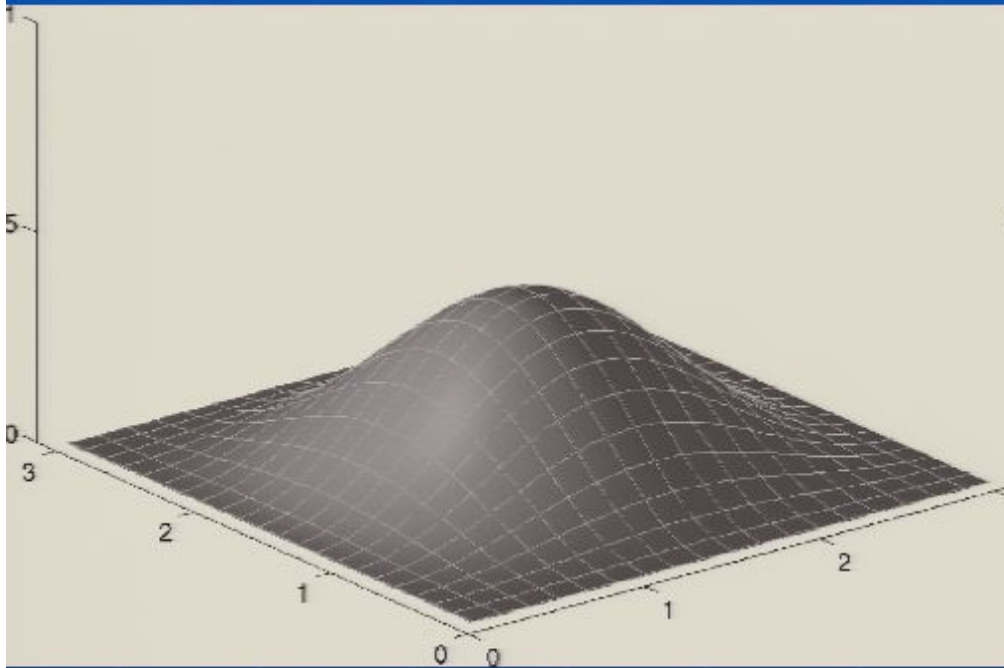
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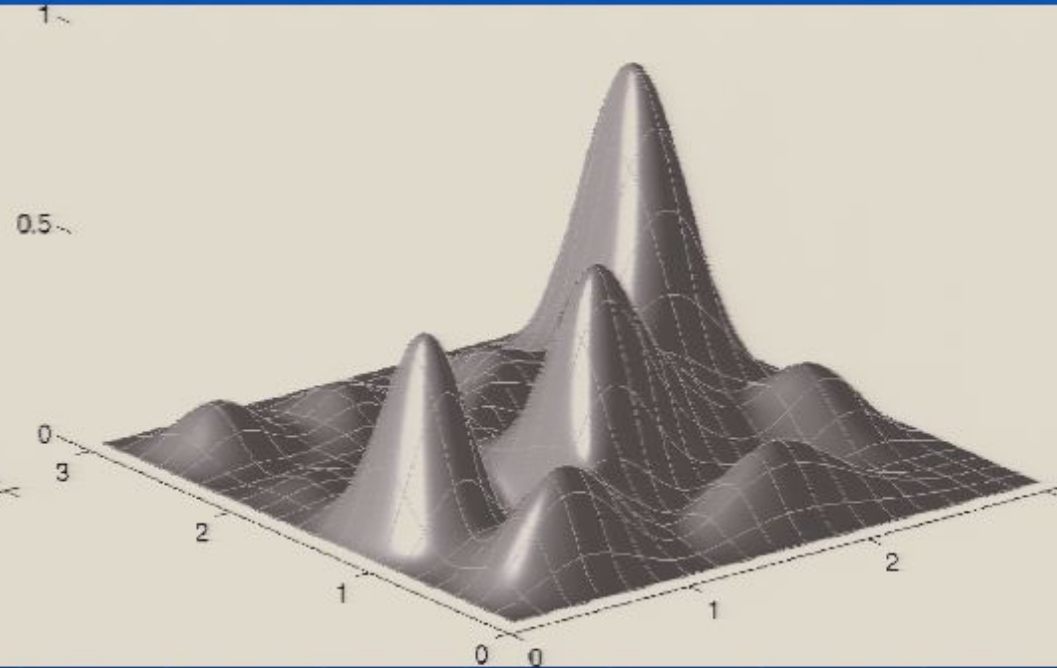
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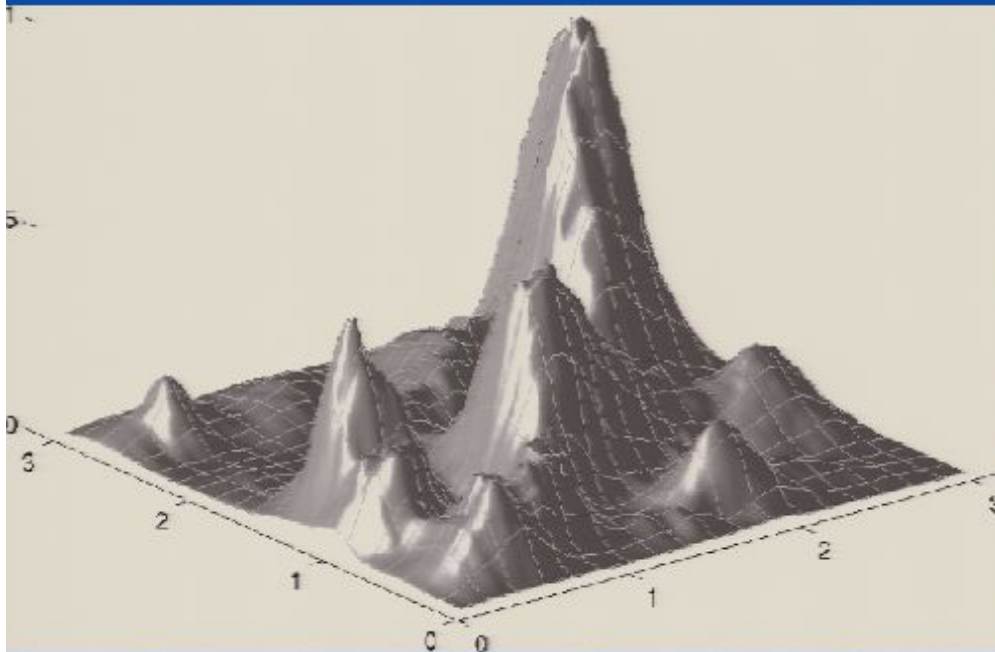
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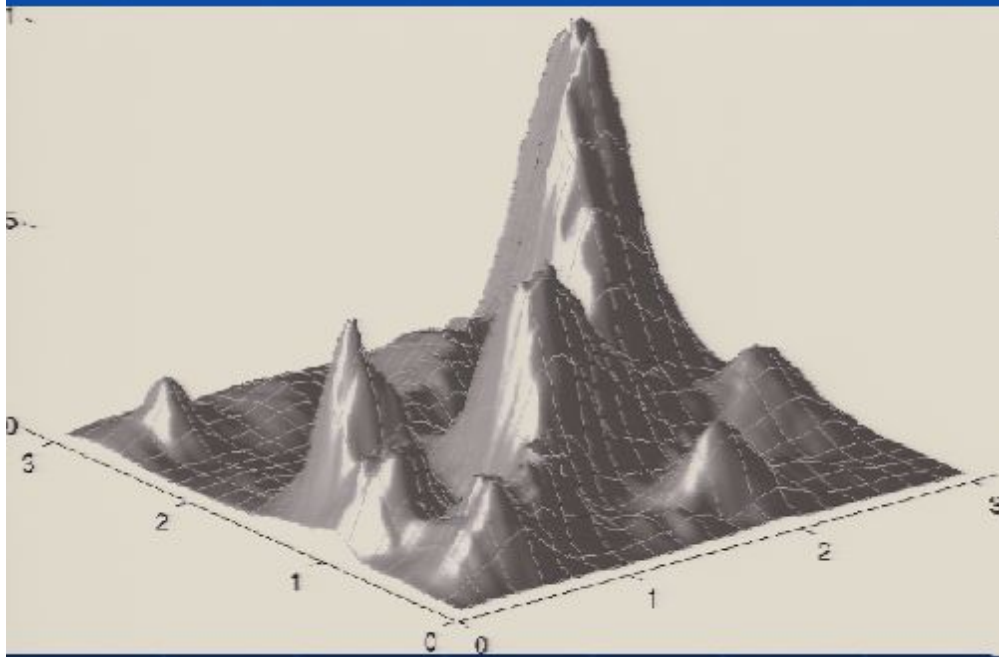


$P(x,y)$  at  $t=4\pi$

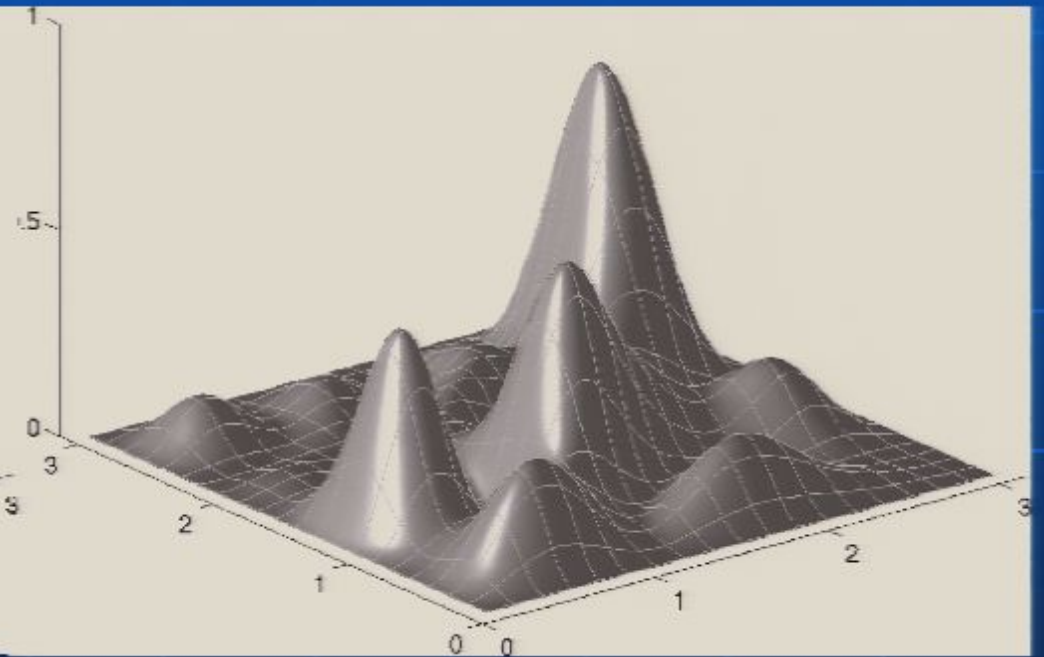


$|\psi(x,y)|^2$  at  $t=4\pi$

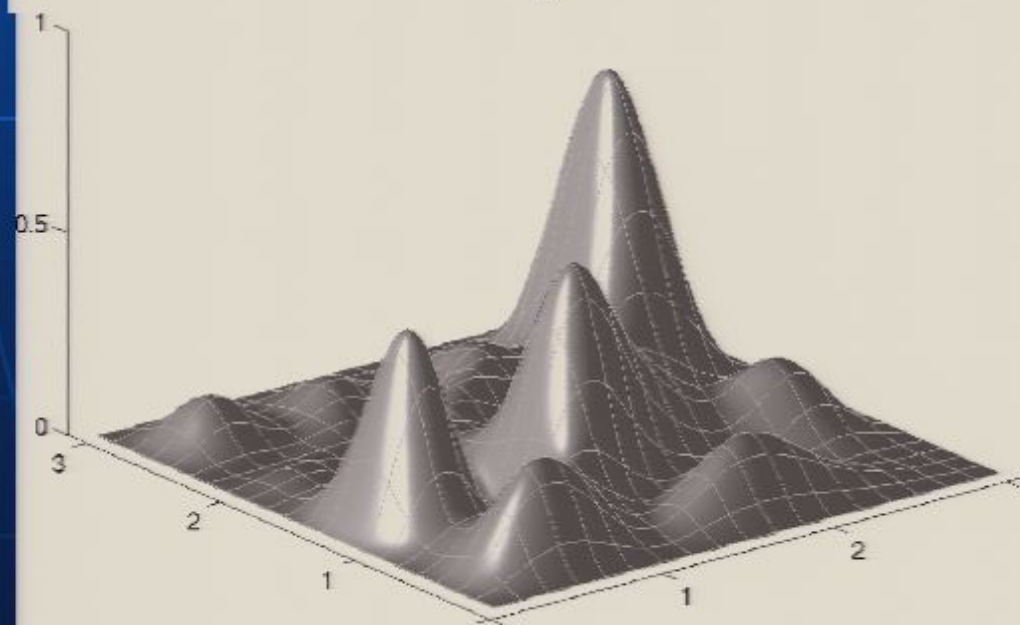
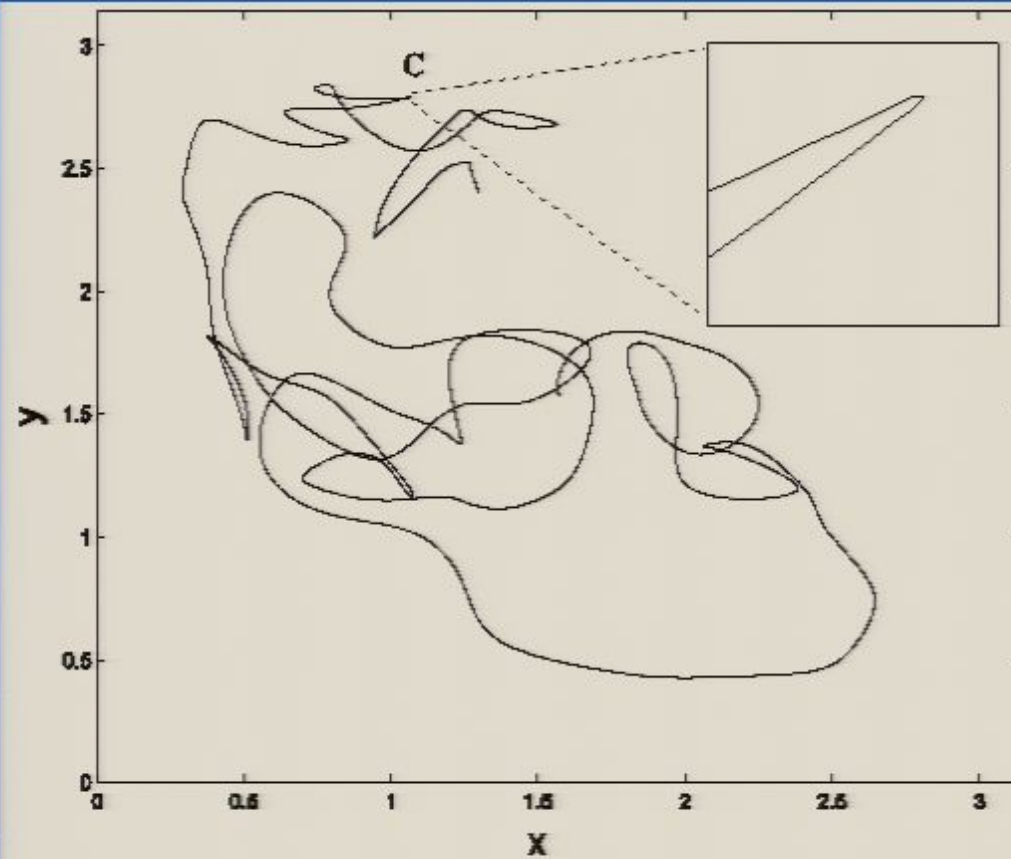
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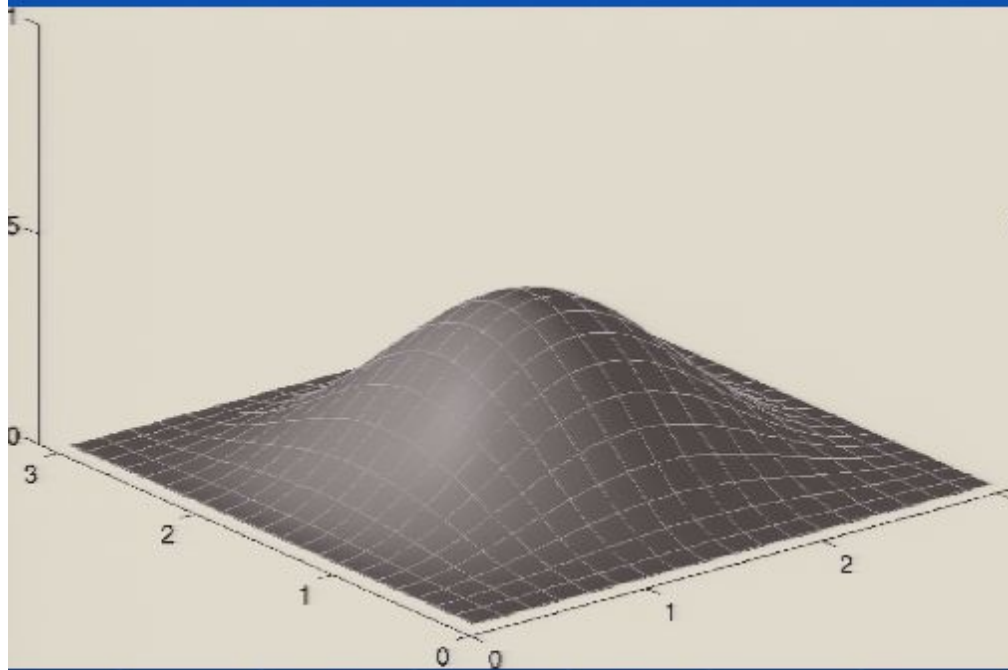
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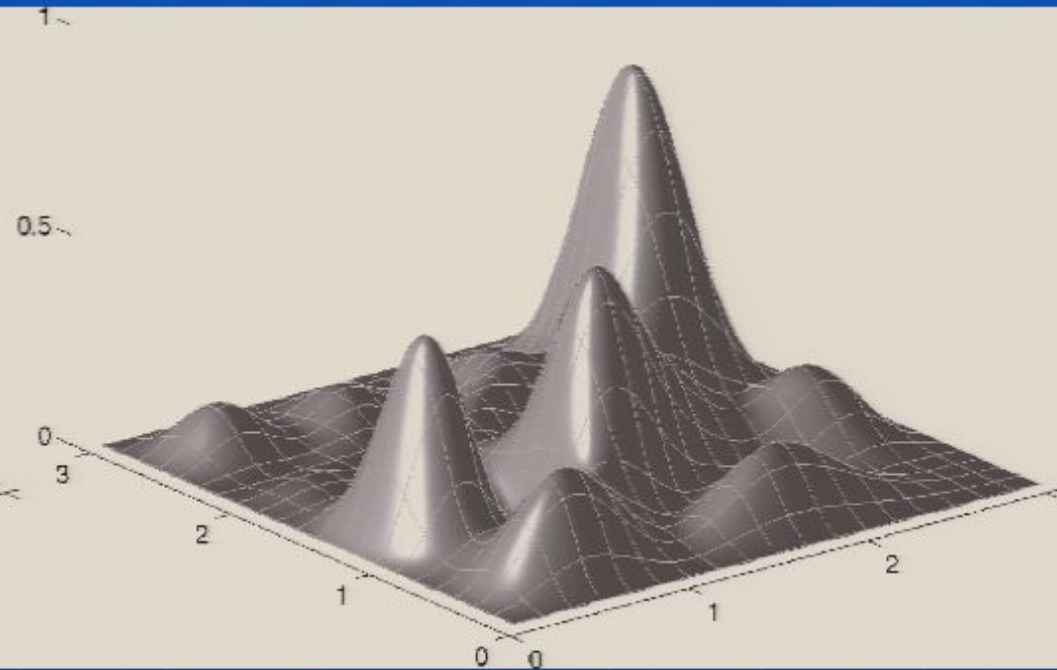




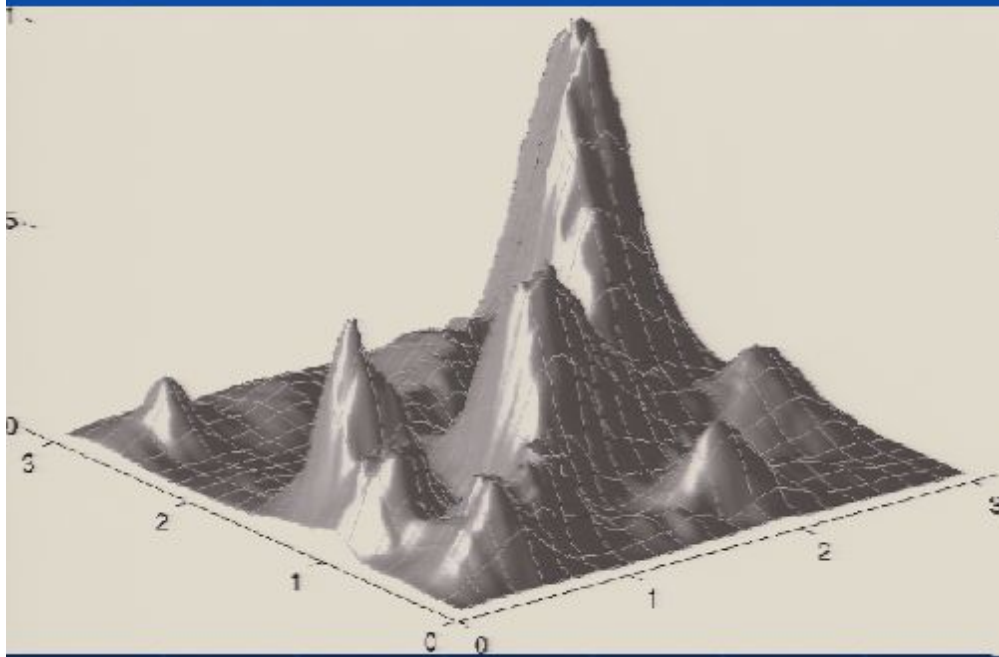
$P(x,y)$  at  $t=0$



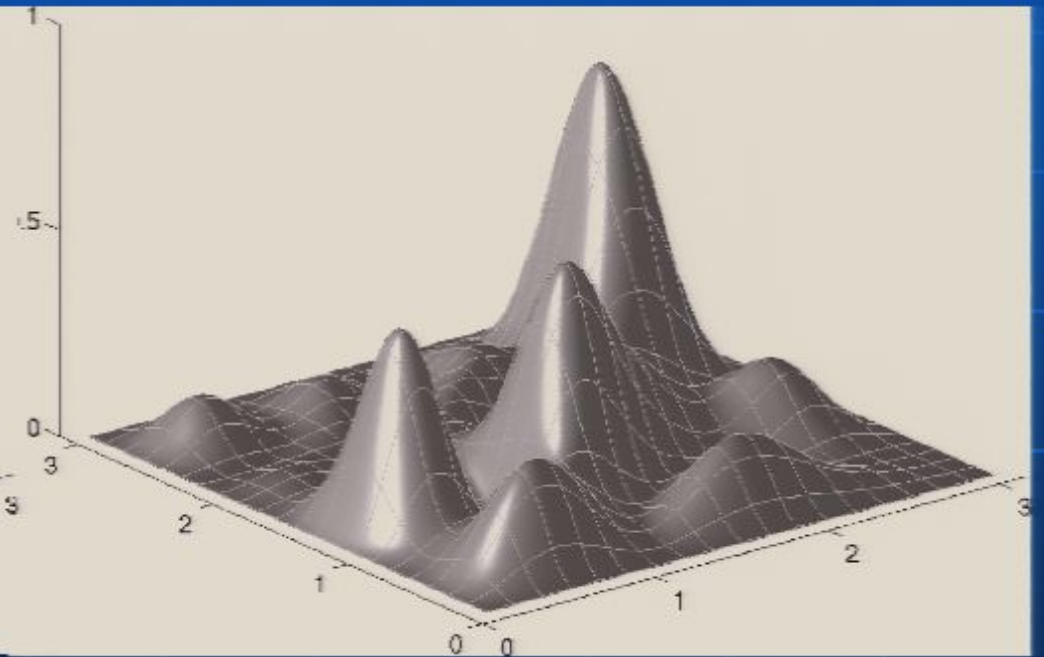
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$P(x,y)$  at  $t=4\pi$



$|\psi(x,y)|^2$  at  $t=4\pi$



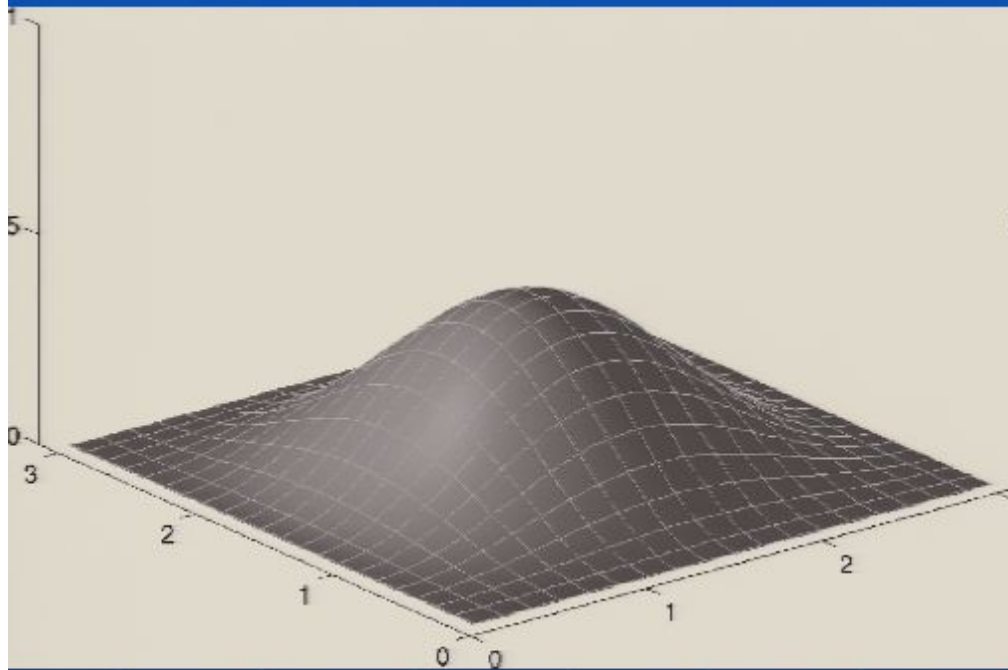


# Conclusion

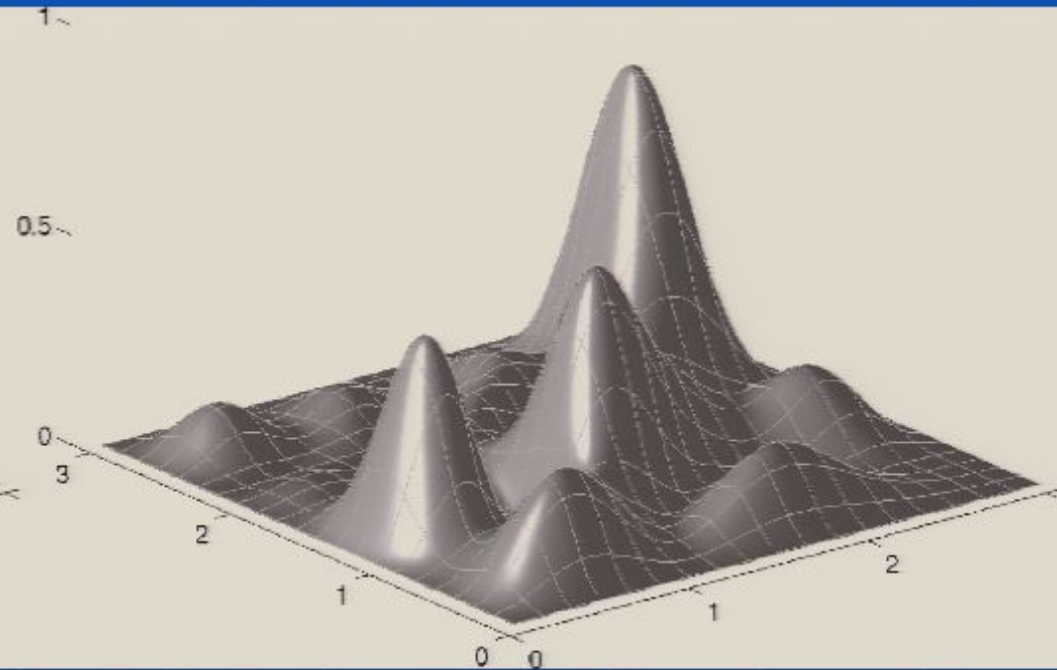
- Quantum theory is an extremely successful theory. Yet it is hard to see how it really can be a fundamental theory.
- Out of the interpretations only the collapse theories and hidden variable theories are precisely formulated without vague concepts like 'classical', microscopic.
- But both of these are different theories with different predictions than quantum theory.



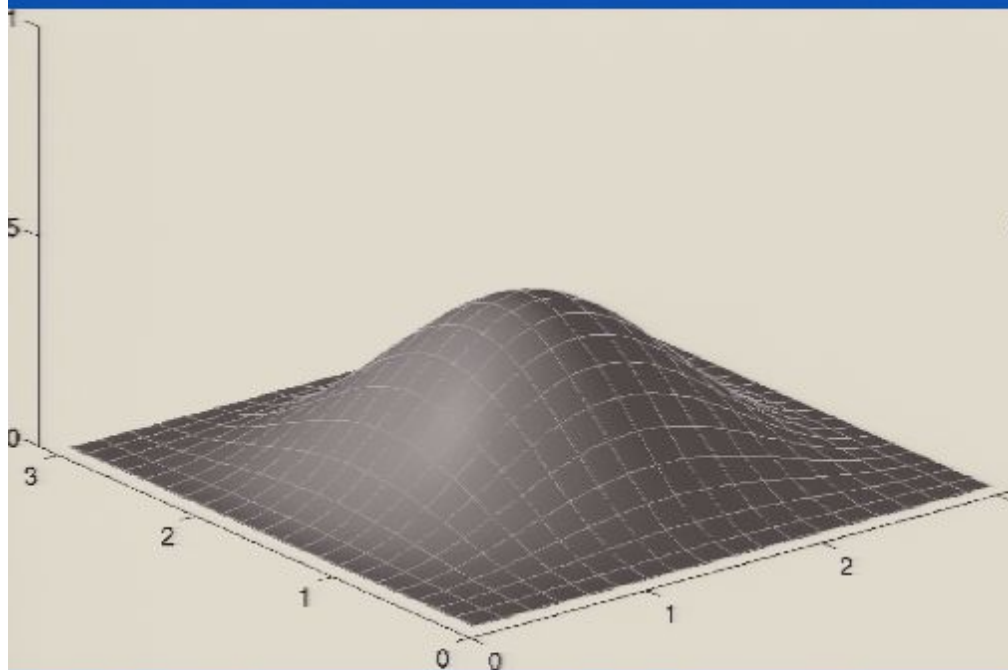
$P(x,y)$  at  $t=0$



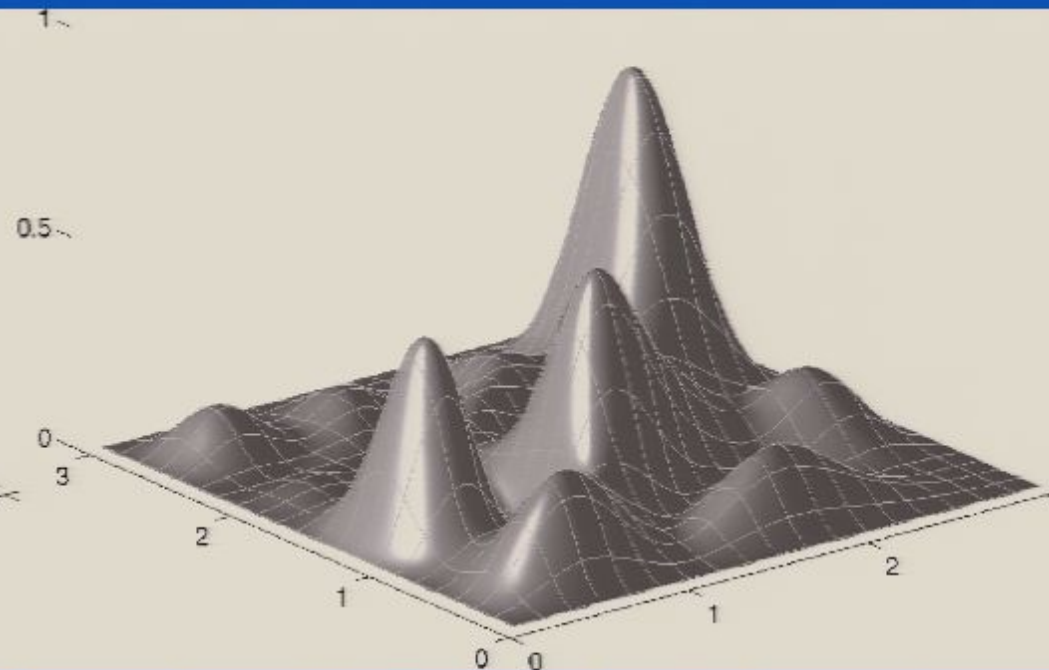
$|\psi(x,y)|^2$  at  $t=0$



$P(x,y)$  at  $t=0$



$|\psi(x,y)|^2$  at  $t=0$

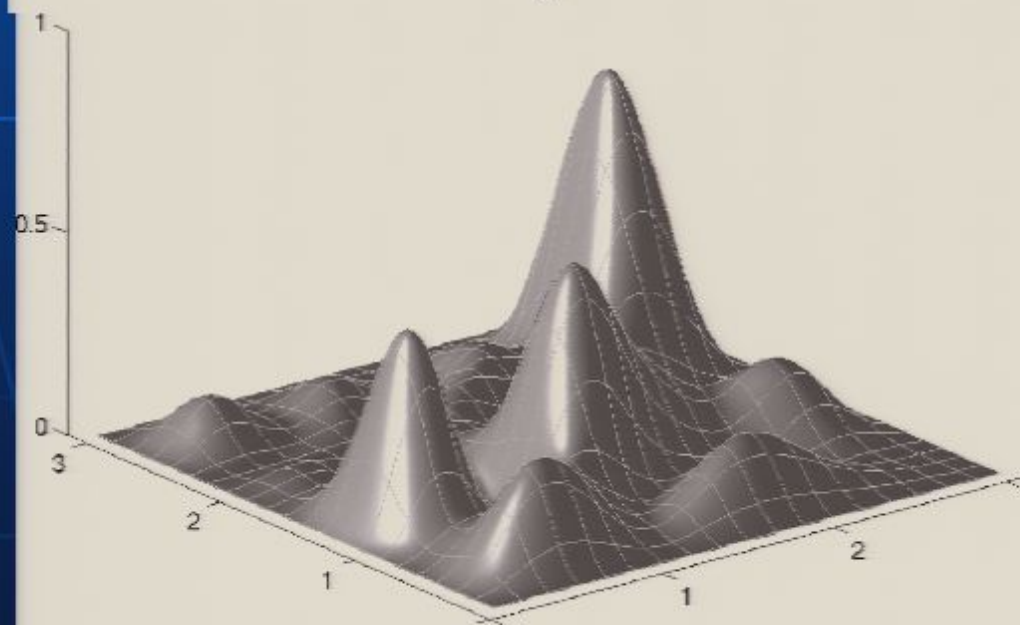
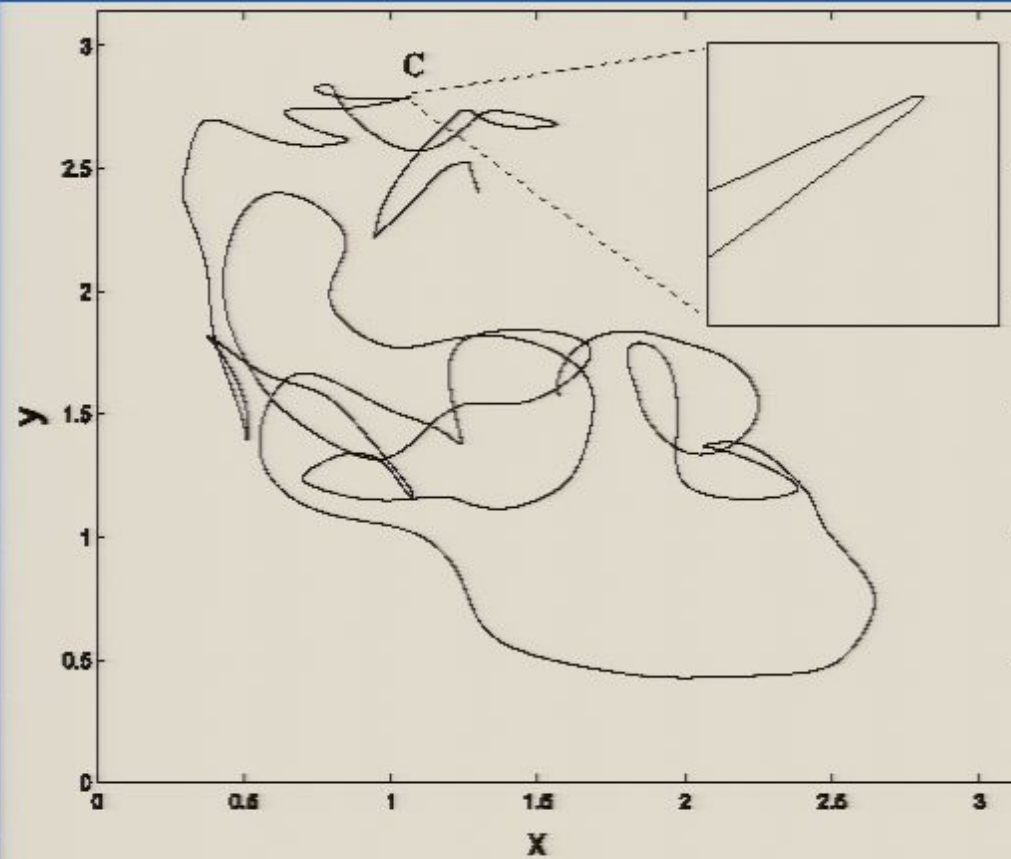


# Conclusion

- Quantum theory is an extremely successful theory. Yet it is hard to see how it really can be a fundamental theory.
- Out of the interpretations only the collapse theories and hidden variable theories are precisely formulated without vague concepts like 'classical', microscopic.
- But both of these are different theories with different predictions than quantum theory.

End of slide show, click to exit.





Outline Slides



**Good News**

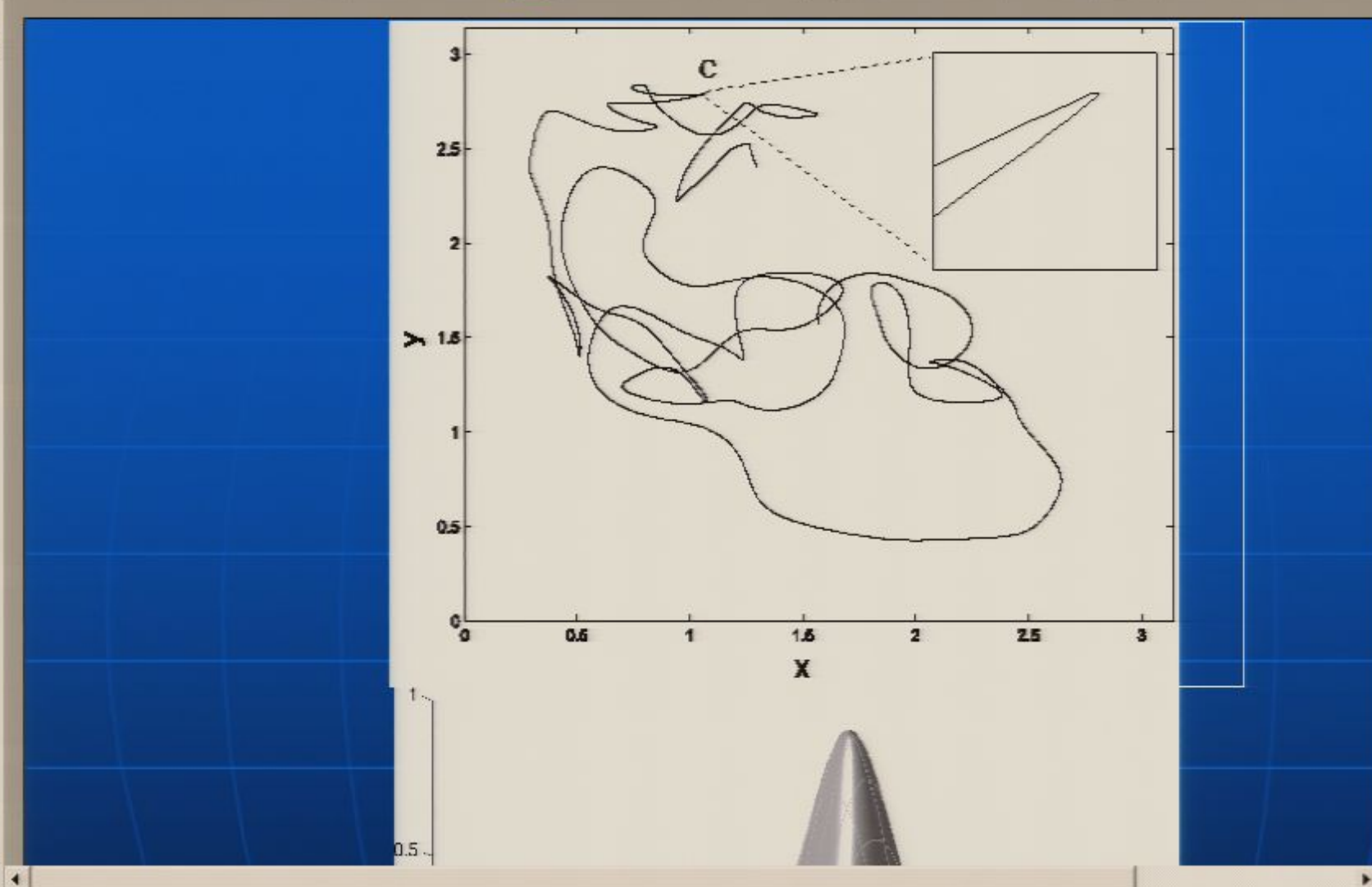
The theory is completely well defined, even **deterministic**, reproduces all the predictions of quantum theory (it also includes quantum theory and the superposition principle is still valid).  
 Call it a much richer theory with quantum theory emerging only in quantum equilibrium.  
 Explains the quantum statistics as a feature of quantum equilibrium.

**Problems**

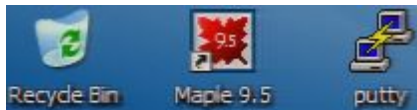
- The universe according to this theory seems rather strange. There are too things that make up the world: (i) the particles in 3D space (ii) the wavefunction that "lives" in all D configuration space.
- The wavefunction is fundamentally unobservable. The world we see is represented by the configuration  $X(t)$  just as in Newtonian physics.
- Empty wave problem.

**Conclusion**

- Quantum theory is an extremely successful theory. Yet it is hard to see how it really can be a fundamental theory.
- Out of the interpretations only the collapse theories and hidden variables theories are precisely formulated without vague concepts like "classical", "microscopic".
- All sorts of these are different theories with different predictions than quantum theory.



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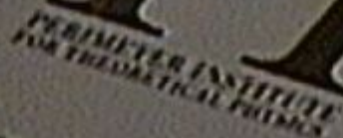
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State University, Philadelphia, Pennsylvania, U.S.A.

**Keywords:** *Self-esteem, self-esteem threat, self-esteem threat sensitivity, self-esteem threat sensitivity scale, self-esteem threat sensitivity scale-2*

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2002 2003 2004

**Keywords:** child sexual abuse; disclosure; legal system; police; social workers

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Abstracts 243-244

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Small Polymers: Evidence for Post-Extrusion and Post-Extrusion

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