

Title: Interpretation of Quantum Theory: Lecture 25

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Abstract:

Spring Seminars on
Complexity and Networks

May 13, — June 16, 2005

PI, Thursdays, 2-5 p.m.

What does the classical limit
tell us about the significance
(interpretation)

tells us about the significance (interpretation
of states?

possibilities

- ① Complete description of reality
→ state maps onto everything
that we think/know is real.

② Partial description of what to read

② Partial description of what is real
eg debringer Broken

know it real.

② A states give a
Partial description of what is real
eg debringer Brahman

③ A states have nothing real about their
Statistical Information only

② States give a
Partial description of what is real
eg. de Broglie-Bohm

③ States have nothing real about them.
Statistical Information only.

Ehrhard (1927)

③ states have nothing real about them.
Statistical Information only.

Ehrenfest (1927)

$$\frac{d\langle \hat{q} \rangle}{dt} = \frac{\langle \hat{p} \rangle}{m} \quad \langle \hat{q} \rangle \equiv \langle \psi | \hat{q} | \psi \rangle$$

$$\frac{d\langle \hat{p} \rangle}{dt} \rightarrow \langle F(\hat{q}) \rangle \equiv \left\langle \frac{dV}{d\hat{q}} \right\rangle_{\hat{q}}$$

$$F(q) = F(\langle q \rangle) + (q - \langle q \rangle) \left. \frac{dF}{dq} \right|_{\bar{q}} + \frac{(q - \langle q \rangle)^2}{2!} \left. \frac{d^2 F}{dq^2} \right|_{\bar{q}} + \dots$$

$$\langle F(q) \rangle =$$

$$F(q) = F(\langle q \rangle) + (q - \langle q \rangle) \left. \frac{dF}{dq} \right|_{q=\langle q \rangle} + \frac{(q - \langle q \rangle)^2}{2!} \left. \frac{d^2 F}{dq^2} \right|_{q=\langle q \rangle} + \dots$$

$$\langle F(q) \rangle = F(\langle q \rangle) + \left\langle \frac{(q - \langle q \rangle)^2}{2} \right\rangle \left. \frac{d^2 F}{dq^2} \right|_{q=\langle q \rangle} + \dots$$

Expand about q expectation value,

$$F(q) = F(\langle q \rangle) + (q - \langle q \rangle) \left. \frac{dF}{dq} \right|_{q=\langle q \rangle} + \frac{(q - \langle q \rangle)^2}{2!} \left. \frac{d^2 F}{dq^2} \right|_{q=\langle q \rangle} + \dots$$

$$\langle F(q) \rangle = F(\langle q \rangle) + \left\langle \frac{(q - \langle q \rangle)^2}{2} \right\rangle \left. \frac{d^2 F}{dq^2} \right|_{q=\langle q \rangle} + \dots$$

Expand about q expectation value,

$$F(q) = F(\langle q \rangle) + (q - \langle q \rangle) \left. \frac{dF}{dq} \right|_{q=\langle q \rangle} + \frac{(q - \langle q \rangle)^2}{2!} \left. \frac{d^2 F}{dq^2} \right|_{q=\langle q \rangle} + \dots$$

$$\langle F(q) \rangle = F(\langle q \rangle) + \left\langle \frac{(q - \langle q \rangle)^2}{2} \right\rangle \left. \frac{d^2 F}{dq^2} \right|_{q=\langle q \rangle} + \dots$$

but Δq can be very narrow compared to the scale set by $\left. \frac{d^2 V}{dq^2} \right|_{q=\langle q \rangle}$

Expand about q expectation value,

$$F(q) = F(\langle q \rangle) + (q - \langle q \rangle) \left. \frac{dF}{dq} \right|_{q=\langle q \rangle} + \frac{(q - \langle q \rangle)^2}{2!} \left. \frac{d^2F}{dq^2} \right|_{q=\langle q \rangle} + \dots$$

$$\langle F(q) \rangle = F(\langle q \rangle) + \frac{\langle \Delta q^2 \rangle}{2} \left. \frac{d^2F}{dq^2} \right|_{q=\langle q \rangle} + \dots$$

Δq can be very narrow

Set by $\frac{d^2V}{dq^2} \sim \omega^2$

fluctuation compared to the scale

→ can be negligible for macroscopic system

$$\frac{d\langle p \rangle}{dt} = \frac{\langle p \rangle}{m}$$
$$\frac{d\langle p \rangle}{dt} = F(\langle q \rangle)$$

$$\frac{d\langle q \rangle}{dt} = \frac{\mathcal{Q}}{m}$$

$$\frac{d\langle q \rangle}{dt} = F(\langle q \rangle)$$

Free particle

$$|g\rangle \quad t = 10^{10} \text{ years}, \quad \Delta q(t) \approx 1 \text{ cm}$$

Start from narrow wave packet before $\Delta q(0) \approx 1 \text{ \AA}$

$$\frac{d\langle \mathbf{q} \rangle}{dt} = \frac{\langle \mathbf{p} \rangle}{m}$$

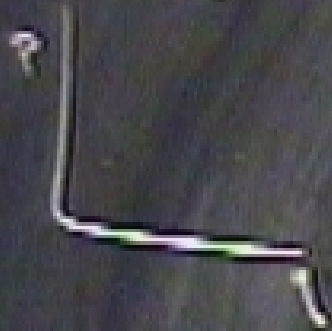
$$\frac{d\langle \mathbf{p} \rangle}{dt} = \mathbf{F}(\langle \mathbf{q} \rangle)$$

Free particle

$|g\rangle$. $t = 10^{19}$ years, $\Delta q(t) \approx 1 \text{ cm}$

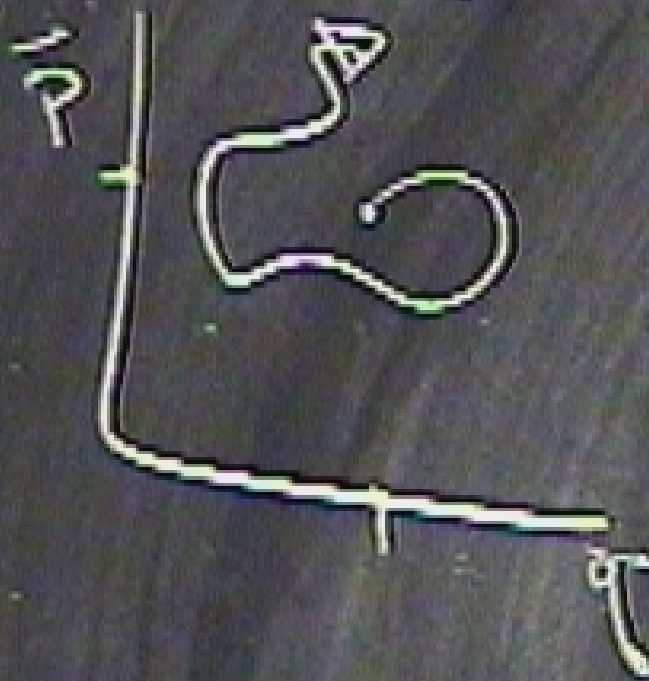
Start from narrow wave packet $\Delta q(0) \approx 1 \text{ \AA}$ before

Classical Chaos

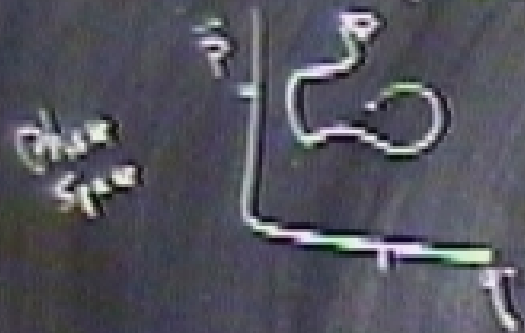


Classical Chaos

Phase
Space



Classical Chaos



Hamiltonian
Systems

Classical Chaos



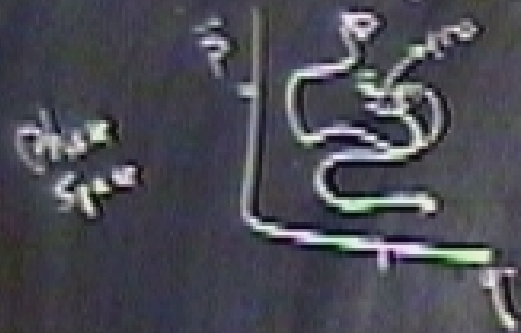
$\bar{x} = (q, p)$ Hamiltonian Systems

$$d(\bar{x}, \bar{y}) =_{\text{def}} \|\bar{x} - \bar{y}\|$$

$$d(\bar{x}, \bar{x}_0) = d(\bar{x}_0, \bar{x}_0) e^{\lambda t}$$

λ = Lyapunov exponent

Classical Chaos



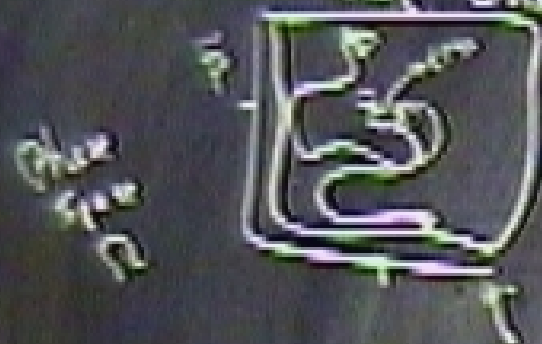
$\vec{x} = (q, p)$ Hamiltonian Systems

$$d(\vec{x}, \vec{y}) = \|\vec{x} - \vec{y}\|$$

$$d(\vec{x}, \vec{y}) = d(\vec{x}_0, \vec{y}_0) e^{\lambda t}$$

λ = Lyapunov exponent

Classical Chaos



Hamiltonian
Systems

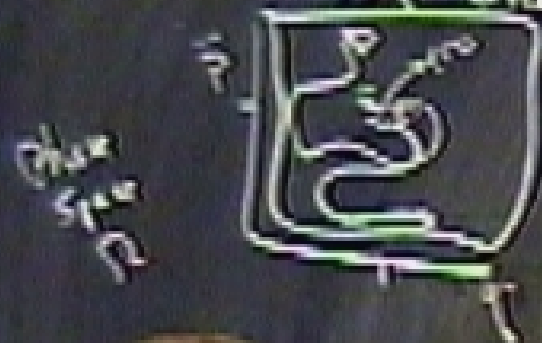
$$d(\bar{x}, \bar{y}) = \|\bar{x} - \bar{y}\|$$

$$d(\bar{x}, \bar{y}) \approx d(\bar{x}, \bar{y}_0) e^{\lambda t}$$

λ = Lyapunov exponent

can only predict
 $d \leq d_{\text{dim}}(M)$

Classical Chaos



$\vec{x} = (q, p)$ Hamiltonian Systems

$$(\vec{x}, t) \rightarrow |\vec{x} - \vec{x}'|$$

$$d(\vec{x}, \vec{x}') = d(\vec{x}_0, \vec{x}'_0) e^{\lambda t}$$

λ = Lyapunov exponent

$$t \approx \frac{1}{\lambda} \log\left(\frac{d(t)}{d_0}\right)$$

can only predict
 $d \approx d_0 e^{\lambda t}$

Expand about $\bar{x}$

$$F(y) = F(\bar{x}) + (y - \bar{x}) \left. \frac{dF}{dx} \right|_{\bar{x}} + \dots$$

Expand about $\bar{x}_c$

$$\langle F(q) \rangle \approx F(\bar{x}_c) + (\langle p \rangle - x_c(t)) \left. \frac{dF}{dq} \right|_{\bar{x}_c(t)} + \dots$$

$$d(\langle q \rangle - q_c, \langle p \rangle - p_c)$$

Expand about $\bar{x}_c$
 $\langle F(q) \rangle \approx F(x_c) + (\langle q \rangle - x_c) \left. \frac{dF}{dq} \right|_{x_c} + \dots$

$$d(\langle q \rangle - q_c, \langle p \rangle - p_c)$$

$\rightarrow$ dynamics (growth rate) are determined
 by $\left. \frac{dF}{dq} \right|_{x_{cr}}$

Expand about $\bar{q}_c$

$$\langle F(q) \rangle = F(\bar{q}) + (\bar{p} - \bar{q}_c) \left. \frac{dF}{dq} \right|_{\bar{q}_c} + \dots$$

$$d(\langle q \rangle - q_c, \langle p \rangle - p_c)$$

→ dynamics (growth rate) are determined
by $\left. \frac{dF}{dq} \right|_{\bar{q}_c}$

$$\frac{dq_i}{dt} = \frac{\partial H}{\partial p_i}$$

$$\frac{dp_i}{dt} = -\frac{\partial H}{\partial q_i}$$

$$\bar{X} = (q_1, p_1, \dots, q_n, p_n)$$

Expand about $\bar{x}_0$

$$\langle F(q) \rangle = F(x) + (\langle p \rangle - x_0(t)) \left. \frac{dF}{dq} \right|_{x_0(t)}$$

$$d(\langle q \rangle - q_0, \langle p \rangle - p_0)$$

→ dynamics (growth rate) are determined
by $\left(\left. \frac{\partial H}{\partial q} \right|_{x_0}, \frac{\partial H}{\partial p} \right)$

Expand about $\bar{x}_c$

$$\langle F(q) \rangle = F(x) + (\bar{q} - x_c(t)) \left. \frac{dF}{dq} \right|_{x_c(t)} + \dots$$

$d(\langle q \rangle - q_c, \langle p \rangle - p_c)$ = diff. quantum expectation values
 + classical phase space point
 → dynamics (growth rate) are determined

by $\left(\left. \frac{\partial H}{\partial q} \right|_{x_c}, \left. \frac{\partial H}{\partial p} \right|_{x_c} \right)$

Chaos → exponential growth of differences

Expand about $\bar{q}$

$$\langle F(q) \rangle = F(\bar{q}) + (\bar{q} - q_c(t)) \left. \frac{dF}{dq} \right|_{q_c(t)} + \dots$$

$$\left[\frac{d}{dt} (\langle q \rangle - q_c, \langle p \rangle - p_c) \right] = \text{diff. quantum expectation values \& classical phase space point}$$

→ dynamics (growth rate) are determined

$$\text{by } \left(\left. \frac{\partial H}{\partial q} \right|_{q_c}, \left. \frac{\partial H}{\partial p} \right|_{p_c} \right)$$

Chaos → exponential growth of differences

→ $\langle \Delta q(t) \rangle$ grows exponentially fast

$$d_{\text{LC}} \sim e^{\lambda t}$$

$$\langle \Delta q \rangle \sim e^{\lambda t}$$

$$\frac{d\langle \mathbf{p} \rangle}{dt} = \frac{\langle \mathbf{F} \rangle}{m}$$

$$\frac{d\langle \mathbf{p} \rangle}{dt} = \langle \mathbf{F}(\mathbf{q}) \rangle = \int \mathbf{F}(\mathbf{q}) \rho(\mathbf{q}) d\mathbf{q}$$

Free particle

$|\mathbf{q}| \sim 10^{19} \text{ years}, \Delta \mathbf{q}(t) \sim 1 \text{ cm}$

Start from narrow wave packet before
 $\Delta \mathbf{q}(0) \sim 1 \text{ \AA}$

$$\frac{d\langle q \rangle}{dt} = \frac{\langle \dot{q} \rangle}{m}$$

$$\frac{d\langle q \rangle}{dt} = F(\langle q \rangle) + \Delta q$$

$\Delta q \sim$ diameter of nucleus
 $t \sim 10^{-22}$ sec

Free particle

$|g\rangle$

$t \sim 10^{-18}$ years

$\Delta q(t) \sim 1$ cm

Start from

narrow wave packet

before

$\Delta q(t) \sim 1 \text{ \AA}$

$\Delta q \sim \text{diameter of satellite}$
 $t \sim 20 \text{ years.}$

Classical dynamics for knowledge

Levinson 19th century

Classical dynamics for knowledge

• Liouville 19^{th} century

Eq. $\dot{q}$

$\rightarrow$ Eq. $\dot{p}$

τ



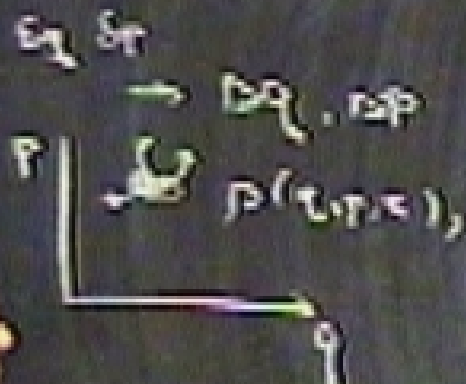
$\rho(q, p, \tau)$

)

q

Classical dynamics for knowledge

Lagrangian M^{th} creating



unitary operator $U(t)$ $\rho(q,p,0) \rightarrow \rho(q,p,t)$

$$\rho(q,p,t) = U^\dagger \rho(q,p,0) U$$

$$\frac{\partial \rho(q,p,t)}{\partial t} = \{H(q,p), \rho\}$$

$$[A, B] = \frac{\partial A}{\partial q} \frac{\partial B}{\partial p} - \frac{\partial A}{\partial p} \frac{\partial B}{\partial q}$$

$$[\hat{A}, \hat{B}] = i\hbar [A, B]$$

$$O(q, p) \quad \text{is} \quad \begin{matrix} O=q \\ O=p \end{matrix}$$

$$\langle O \rangle = \int d\phi \, O(q, p) \rho(q, p, t)$$

cal dynamics for knowledge.

ville 19th century

Sp

→ DQ, DP

unitary operator
 $U_t = e^{-iHt}$, $t \in \mathbb{R}$

$$\rho(q, p, t) = U_t^\dagger \rho(q, p, 0) U_t$$

$$\frac{\partial \rho(q, p, t)}{\partial t} = \{ H(q, p), \rho \}$$

$= \int dx \delta(x - y(t)) \rho(x, y(t))$

$$\{A, B\} = \frac{\partial A}{\partial q} \frac{\partial B}{\partial p} - \frac{\partial A}{\partial p} \frac{\partial B}{\partial q}$$

$\{A, B\} = (A, B)$

cal dynamics for knowledge.

villc 19th century

Sp

→ DQ, DP

$\rho(q, p, t)$

q

unitary operator
 $U_t = e^{-iHt/\hbar}$, $t \in \mathbb{R}$

$$\rho(q, p, t) = U_t^\dagger \rho(q, p, 0) U_t$$

$$\frac{\partial \rho(q, p, t)}{\partial t} = \{ H(q, p), \rho \}$$

$= \int dx \delta(x - y(t, x)) \rho(x, 0)$

$$[A, B] = \frac{\partial A}{\partial q} \frac{\partial B}{\partial p} - \frac{\partial A}{\partial p} \frac{\partial B}{\partial q}$$

$$[\hat{A}, \hat{B}] = i\hbar \{A, B\}$$

$$O(q, p) \rightarrow \begin{matrix} O + q \\ O + p \end{matrix}$$

$$\langle O \rangle_c = \int dq dp O(q, p) \rho(q, p, t)$$

$$\frac{d\langle q \rangle_c}{dt} = \langle \frac{p}{m} \rangle_c$$

$$\frac{d\langle p \rangle_c}{dt} = \langle F(q) \rangle_c = F(q_c) + \frac{\Delta q^2}{2} \left. \frac{\partial^2 F}{\partial q^2} \right|_{q=q_c}$$

$$\Delta q^2 = \langle q^2 \rangle_c - \langle q \rangle_c^2$$

$$O(q, p) \rightarrow \begin{matrix} O = q \\ O = p \end{matrix}$$

$$\langle O \rangle_c = \int dq dp \, O(q, p) \rho(q, p, t)$$

$$\frac{d\langle q \rangle_c}{dt} = \langle \frac{p}{m} \rangle_c$$

$$\frac{d\langle p \rangle_c}{dt} = \langle F(q) \rangle_c = F(q, \lambda) + \frac{\Delta q^2}{2} \frac{\partial^2 F}{\partial q^2} \bigg|_{q=q_2} + \dots$$

$$\Delta q^2 = \langle q^2 \rangle_c - \langle q \rangle_c^2$$

$$O(q, p) \quad \text{or} \quad \begin{matrix} O=q \\ O=p \end{matrix}$$

$$\langle O \rangle_c = \int dq dp \, O(q, p) \rho(q, p, t)$$

$$\frac{d\langle q \rangle_c}{dt} = \frac{\langle p \rangle_c}{m}$$

$$\frac{d\langle p \rangle_c}{dt} = \langle F(q) \rangle_c = \bar{F}(q, \lambda) + \frac{M^2}{2} \left. \frac{\partial^2 F}{\partial q^2} \right|_{q=q_2} + \dots$$

$$M^2 F \langle q^2 \rangle_c - \langle q^2 \rangle_c$$

Classical dynamics for knowledge

Liouville M^N coordinates

Eq. of motion $\rightarrow$ (q, p)



unitary operator $U_t = e^{-iHt}$

$$\rho(q, p, t) = U_t^\dagger \rho(q, p, 0)$$

$$\frac{\partial \rho(q, p, t)}{\partial t} = \{H(q, p), \rho\}$$

$$[A, B] = \frac{\partial A}{\partial q} \frac{\partial B}{\partial p} - \frac{\partial A}{\partial p} \frac{\partial B}{\partial q}$$

$$\frac{d\langle q \rangle_c}{dt} = \frac{\langle p \rangle_c}{m}$$

$$\frac{d\langle F(q) \rangle_c}{dt} = \langle F(q) \rangle_c = F(\langle q \rangle_c) + \frac{\langle \Delta q^2 \rangle_c}{2} \frac{d^2 F}{dq^2} \bigg|_{q=\langle q \rangle_c} + \dots$$

$\Delta q^2 = \langle q^2 \rangle_c - \langle q \rangle_c^2$

Start
from narrow
wave packet



$$P(\mathbf{y}, \mathbf{z}) = \int \mathbf{q}(\mathbf{z}) P(\mathbf{y}, \mathbf{z}) d\mathbf{z}$$

$$\rho(q, p, t) = \int \langle q, p | \hat{\rho} | q, p \rangle e^{i\phi}$$

$$\frac{\partial \rho(q, p, t)}{\partial t} = \{H, \rho(q, p, t)\} + \hbar$$



$$\rho(q) = \int dy \langle q - \frac{y}{2} | \hat{\rho} | q + \frac{y}{2} \rangle e^{i p y}$$

$$\frac{\partial \rho_n(q, p, t)}{\partial t} = \{ H, \rho_n(q, p, t) \} + \sum_{m=1}^{\infty} \left(\frac{H}{2} \right)^{2m} \frac{(-1)^m}{(2m+1)!} \frac{\partial^{2m+1} \rho_n}{\partial p^{2m+1}} + \frac{\partial^{2m+1} H}{\partial q^{2m+1}}$$

$$\rho(x) = \int dy \langle q - \frac{y}{2} | \hat{p} | q + \frac{y}{2} \rangle e^{i p y}$$

$$\frac{\partial \rho_n(q, p, t)}{\partial t} = \{ H, \rho_n(q, p, t) \} + \sum_{m=1}^{\infty} \left(\frac{H^{(2m)}}{(2)} \frac{(-1)^m}{(2m+1)!} \right) \frac{\partial^{2m+1} \rho_n}{\partial p^{2m+1}} + \frac{\partial^{2m+1} H}{\partial q^{2m+1}}$$

$$H = \underline{\underline{P_n^2}} + V(q)$$

$$\rho(q, p, t) = \int \langle q - \frac{1}{2} | \hat{p} | q + \frac{1}{2} \rangle e^{i p q}$$

$$\frac{\partial \rho(q, p, t)}{\partial t} = \{ H, \rho(q, p, t) \} + \sum_{n=1}^{\infty} \left(\frac{h}{2\pi i} \right)^n \frac{(-1)^n}{(2n-1)!} \frac{\partial^{2n+1} \rho}{\partial q^{2n+1}} = \frac{\partial^{2n+1} H}{\partial q^{2n+1}}$$

$$\text{Sym} \quad H = \frac{p^2}{2m} + V(q)$$

$$\frac{d \langle A(q, p) \rangle}{dt}$$

$$\rho(q, p, t) = \int \langle q, p | \hat{\rho} | q, p \rangle e^{i\phi}$$

$$\frac{\partial \rho(q, p, t)}{\partial t} = \{H, \rho(q, p, t)\} + \sum_{n=1}^{\infty} \left(\frac{1}{2^n} \right) \frac{(-1)^n}{(2n+1)!} \frac{\partial^{2n+1} \rho}{\partial p^{2n+1}}$$

$\hbar \rightarrow 0 \quad \frac{\hbar}{2m} \rightarrow 0$

Symplectic $H = \frac{p^2}{2m} + V(q)$

$$\frac{d\rho}{dt} = \left\langle \{H, \rho(q, p, t)\} \right\rangle + \sum_{n=1}^{\infty} \left(\frac{1}{2^n} \right) \frac{(-1)^n}{(2n+1)!} \left\langle \frac{\partial^{2n+1} \rho}{\partial p^{2n+1}} \right\rangle$$

$$\rho(q, p) = \int \langle q - \frac{1}{2} | \delta | q + \frac{1}{2} \rangle e^{i p x}$$

$$\frac{\partial \rho(q, p, t)}{\partial t} = \{ H_L, \rho(q, p, t) \} + \sum_{n=1}^{\infty} \left(\frac{h}{2\pi i} \right)^n \frac{(-1)^n}{(2n+1)!} \frac{\partial^{2n+1} \rho}{\partial p^{2n+1}}$$

Sym, $H = \underline{\hat{p}}^2 + V(q)$

$\frac{\partial^{2n+1} H}{\partial p^{2n+1}}$

$$\frac{d \langle A(q, p) \rangle}{dt} = \left\langle \left\{ H_L, \rho(q, p, t) \right\} \right\rangle + \sum_{n=1}^{\infty} \left(\frac{h}{2\pi i} \right)^n \frac{(-1)^n}{(2n+1)!} \left\langle \frac{\partial^{2n+1} A}{\partial p^{2n+1}} \frac{\partial^{2n+1} H}{\partial p^{2n+1}} \right\rangle$$

$\langle O \rangle = \int d^4 q \rho(q, p, t) O(q, p)$

Classical dynamics for knowledge

Lagrange n^{th} order $E(q, p, t)$ making operators
 $\int_{t_0}^t U_t \cdot dt$ 2.1.11.3

eq. set

$\rightarrow$ DO



$$\rho(q, p, t) = U^t \rho(q, p, 0)$$

$$\frac{\partial \rho(q, p, t)}{\partial t} = \{ H(q, p), \rho \} - \int dx \delta(x - y(t)) \rho(x, 0)$$

$$\{A, B\} = \frac{\partial A}{\partial q} \frac{\partial B}{\partial p} - \frac{\partial A}{\partial p} \frac{\partial B}{\partial q}$$

$$[\hat{A}, \hat{B}] = i\hbar \{A, B\}$$

Classical dynamics for knowledge

Lagrange m^{th} order $E(q, p, t)$ $\rightarrow$ $\int_{t_0}^{t_1} L(q, \dot{q}, t) dt$ $\rightarrow$ $\int_{t_0}^{t_1} L(q, p, t) dt$
 $\rightarrow E_0$
 $\rho(q, p, t) = U^t \rho(q, p, 0)$

$\rho(q, p, t)$
 $\rightarrow$ $\rho(q, p, 0)$

$$\frac{\partial \rho(q, p, t)}{\partial t} = \{H(q, p), \rho\}$$

$$[A, B] = \frac{\partial A}{\partial q} \frac{\partial B}{\partial p} - \frac{\partial A}{\partial p} \frac{\partial B}{\partial q}$$

Classical dynamics for knowledge

Lagrangian M^N coordinates $E(q, p, t)$ ρ probability density

Eq. of motion $\rightarrow$ DQ

$$E(q, p, t) = E_0 + E_1 + \dots$$

$$\rho(q, p, t) = U^t \rho(q, p, 0)$$



$$\frac{\partial \rho(q, p, t)}{\partial t} = \{H(q, p), \rho\} - \sum_i \delta(x - y(t_i)) \rho(t_i)$$

$$\{A, B\} = \frac{\partial A}{\partial q} \frac{\partial B}{\partial p} - \frac{\partial A}{\partial p} \frac{\partial B}{\partial q}$$

$$[A, B] = i\hbar \{A, B\}$$

$d \left(\frac{A_w(p,p)}{dt} \right) =$
 arXiv.org / abs / quant-ph /

- 1) Many many worlds
- 2) Copenhagen
- 3) Or

1) Many many worlds

{ 2) Copenhagen (Bohr, Heisenberg)
+ classical instruments

{ 3) Orthodox (Wigner, Dirac)
+ collapse

4) dEB

1) Many many worlds

{ 2) Copenhagen (Bohr, Heisenberg)
→ classical instruments
→ Orthodoxy (McMinn, Dirac)
→ collapse

de Broglie-Bohm

Statistical Interpretation

Quantum Collapse

- 3) Entanglement (Wigner, Dirac)
→ collapse
- 4) de Broglie-Bohm
- 5) Statistical Interpretation
- 6) Spontaneous Collapse
- 7) Consistent Histories / Decoherent Hist
- 8) Superdeterminism



- 1) Many many worlds
- 2) Copenhagen (Bohr, Heisenberg)
↳ classical instruments
- 3) Orthodox (V. Neumann, Dirac)
↳ collapse
- 4) de Broglie-Bohm
- 5) Statistical Interpretation
- 6) Spontaneous Collapse
- 7) Consistent Histories / Decoherent Hist.
- 8) Superdeterminism

9) many, II, V.

10) Agnostics

11) ~~classical physics~~

11) Shut up + calculate

1) Many many worlds

{ 2) Copenhagen (Bohr, Heisenberg)
+ classical instruments

{ 3) Orthodox (Wigner, Dirac)
→ collapse

4) deBroglie-Bohm

5) Statistical Interpretation

6) Spontaneous Collapse

7) Consistent Histories / Decoherent Hist

8) Superdeterminism

13) None of the above / below / both

9) none of them

10) Agnosticism

11) Shut-up and calculate

11) Shut-up + calculate

12) Dismantling "Real"

- 1) Many many worlds
- 2) Copenhagen (Bohr, Heisenberg)
→ classical instruments
- 3) Orthodox (Wigner, Dirac) → collapse
- 4) deBroglie-Bohm
- 5) Statistical Interpretation
- 6) Spontaneous Collapse
- 7) Consistent Histories / Decoherent Hist
- 8) Superdeterminism
- 9) & Logic Approach
- 10) Non 2. the above / other / ...
- 11) many, IV
- 12) Agnosticism
- 13) Humanism
- 14) Shut up + calculate
- 15) Daintierne "Kultur"

- 1) Many many worlds
- 2) Copenhagen (Bohr, Heisenberg)
→ classical instruments
- 3) Orthodox (Wigner, Dirac)
→ collapse
- 4) deBroglie-Bohm
- 5) Statistical Interpretation
- 6) Spontaneous Collapse
- 7) Consistent Histories / Decoherent Hist
- 8) Superdeterminism
- 9) Epistemic Interpretation
- 10) & Logic Approach
- 11) Non 2 state above / below / part
- 12) many HV
- 13) Agnostics
- 14) ~~Quantum~~ Quantum ~~problem~~
- 15) Shut up + calculate
- 16) Daintierne "Koch"

1) Many many worlds

{2) Copenhagen (Bohr, Heisenberg)
+ classical instruments

{3) Orthodox (Wigner, Dirac)
→ collapse

4) deBroglie-Bohm

5) Statistical Interpretation

6) Spontaneous Collapse

7) Consistent Histories / Decoherent Hist

8) Superdeterminism

15) Epistemic Interpretation
(Bohm, ...)

14) Logic Approach

13) None of the above / other / ...

9) many, ...

12) Agnosticism

11) ...

11) Setup + calculate

10) Discrepancy "kicks"

- 1) Many many worlds
- 2) Copenhagen (Bohr, Heisenberg)
 - + classical instruments
- 3) Orthodox (Wigner, Dirac)
 - collapse
- 4) deBroglie-Bohm
- 5) Statistical Interpretation
- 6) Spontaneous Collapse
- 7) Consistent Histories / Decoherent Hist
- 8) Superdeterminism
- 9) Many Worlds
- 10) Agnosticism
- 11) ~~Stochastic~~ Stochastic ~~collapse~~
- 12) Deeper meaning "Real"
- 13) How to do class/calc/quant
- 14) Logic Approach
- 15) Epistemic Interpretation (Heisenberg, Ind. system)
- 16) Operational Approaches

- 1) Many many worlds
- { 2) Copenhagen (Bohr, Heisenberg)
+ classical instruments
- { 3) Orthodox (Wigner, Dirac)
↳ collapse
- 4) deBroglie-Bohm
- 5) Statistical Interpretation
- 6) Spontaneous Collapse
- 7) Consistent Histories / Decoherent Hist
- 8) Superdeterminism / Anti-Realism
- 11) Operational Approaches
- 15) Epistemic Interpretation
(Bell's, LHC system)
- 14) D Logic Approaches
- 13) How 2 the above / below / both
- 9) many IV
- 10) Agnostics
- 11) Quantum puzzles
- 11) Shut up + calculate
- 12) Deeper meaning "EPR"

- 1) Many many worlds
- 2) Copenhagen (Bohr, Heisenberg)
→ classical instruments
- 3) Orthodox (Wigner, Dirac)
→ collapse
- 4) deBroglie-Bohm
- 5) Statistical Interpretation
- 6) Spontaneous Collapse
- 7) Consistent Histories / Path + Hist
- 8) Superdeterminism / Anti-Realism

- 17) QM is an approximation
- 12) Modal Interpretations
- 16) Operational Approaches
- 15) Epistemic Interpretation
(hidden Φ , info. system)
- 14) Q Logic Approach
- 13) How to do choice/collapse
- 9) many HV
- 10) Agnosticism
- ~~11) Superdeterminism~~
- 11) Shut up & calculate
- 12) Divergence "Bohr"

19) Realistic Approach (Sartre)

1) Many many worlds

{ 2) Copenhagen (Bohr, Heisenberg)
+ classical instruments

{ 3) Orthodox (Wigner, Dirac)
↳ collapse

4) de Broglie-Bohm

5) Statistical Interpretation

6) Spontaneous Collapse

7) Consistent Histories / Decoherent Hist

8) Superdeterminism / Anti-Realism

17) QM is an approximation

12) Model Interpretations

16) Operational Approaches

15) Epistemic Interpretation
(Bell's, Ind. system)

14) D Logic Approaches

13) How to do above / below / both

9) many HV

10) Agnostics

11) Science fiction

11) Shut up + calculate

12) Dawkins 'anti'

19) Inclusion Approach (Sartre)

1) Many many worlds

{ 2) Copenhagen (Bohr, Heisenberg)
+ classical instruments

{ 3) Orthodox (Wigner, Dirac)
→ collapse

4) de Broglie-Bohm

5) Statistical Interpretation

6) Spontaneous Collapse

7) Consistent Histories / Decoherent Hist

8) Superdeterminism / Anti-Realism

17) QM is an approximation

12) Model Interpretations

16) Operational Approaches

15) Epistemic Interpretation
(hidden θ , info. system)

14) Q Logic Approach

13) How to do above / below / both

9) many, IV

12) Agnosticism

~~11) Science as puzzle~~

11) Set up + calculate

12) Deeper meaning "kiss"

19) Realism Approach (Sartre)

1) Many many worlds

{ 2) Copenhagen (Bohr, Heisenberg)

{ 3) Orthodox (Wigner, Dirac)
→ collapse

4) de Broglie-Bohm

5) Statistical Interpretation

6) Spontaneous Collapse

7) Consistent Histories / Decoherent Hist

8) Superdeterminism / Anti-Realism

17) QM is an approximation

12) Model Interpretations

16) Operational Approaches

15) Epistemic Interpretation
(hidden θ , ind. system)

14) $\mathcal{D}$ Logic Approaches

13) How to do above / below / both

9) noneq. HV

10) Agnosticism

11) ~~Stochastic~~ ~~process~~

11) Shut up + calculate

12) Denouncing "class"

14) Realistic Approach (Sartre)

1) Many many worlds

{ 2) Copenhagen (Bohr, Heisenberg)

{ 3) Orthodox (Wigner, Dirac)

4) de Broglie-Bohm

5) Statistical Interpretation

6) Spontaneous Collapse

7) Consistent Histories / Decoherent Hist

8) Superdeterminism / Anti-Realism

15) QM is an approximation

16) Model Interpretations

17) Operational Approaches

18) Epistemic Interpretation (Hofmann, Ind. system)

19) Logic Approaches

20) None of the above / Unknown

21) None of the above

22) Agnosticism

23) Quantum Gravity

24) Still up + calculate

25) Deeper meaning "is"

14) Realism Approach (Sorkin)

1) Many many worlds

{ 2) Copenhagen (Bohr, Heisenberg)

{ 3) Orthodox (von Neumann, Dirac)

4) de Broglie-Bohm

5) Statistical Interpretation

6) Spontaneous Collapse

7) Consistent Histories / Penrose-Hart

8) Superdeterminism / Anti-Relativism

17) QM is an approximation

12) Model Interpretations

16) Operational Approaches

15) Epistemic Interpretation (Bell's theorem, Ind. system)

14) Logic Approach

13) How to do above / below / etc

9) Non-rel. QV

12) Agnosticism

~~11) Superdeterminism~~

11) Shut up + calculate

12) Dealing with "class"

19) Realism Approach (Sartre)

1) Many many worlds

2) Copenhagen (Bohr, Heisenberg)

3) Orthodox (Heisenberg, Dirac)

4) de Broglie-Bohm

5) Statistical Interpretation

6) Spontaneous Collapse

2) Consistent Histories / Decoherent Hist

3) Superdeterminism / Anti-Realism

17) QM non-existence

12) Model Interpretation

16) Operational Approaches

15) Epistemic Interpretation
(Heisenberg, Ind. system)

14) Logic Approach

13) How to describe/observe/interpret

9) none of it

10) Agnosticism

11) Measurement problem

11) Shut up + calculate

12) Deeper meaning "EPR"