Today

- Reminder Double Slit

- Description from "Orthodox" QM
  "Positivist"

- H: Description from "Realist" QM

Formulation of QM in better notation

1) $|\psi\rangle$ - State of the system at any given time specified by some vector ψ that lives in complex vector space "Hilbert Space"

$\Rightarrow$

$|\phi\rangle \leftrightarrow \langle\phi|$ - dual vectors

$\langle\phi|\psi\rangle$ - complex #

think row & column vectors

Observables are (Hermitian) Operators on this space.

Operators $f: |\phi\rangle \to |\phi'\rangle$

② $\mathcal{O}|\phi\rangle = \lambda_\phi |\phi\rangle$

"eigen vector" "eigen value"

$|\phi\rangle$ has definite value of $\mathcal{O}$ w/ value λ_ϕ

~~turns out~~

$$i\hbar \frac{d|\psi\rangle}{dt} = H|\psi\rangle$$

follows from ① & ②

③ If measure $\mathcal{O}$ and $|\psi\rangle$ not an eigenstate of $\mathcal{O}$, then will get λ_{ϕ_i} as outcome w/ prob $|\langle\phi_i|\psi\rangle|^2$

& Now $|\psi\rangle \longrightarrow |\phi_i\rangle$

How does this map on to the notation we've been using?

$|x\rangle$ - State w/ well-defined position x

$\langle x|\psi\rangle$ - Complex function of x

$\equiv \psi(x)$

$$P(x) = |\langle x|\psi\rangle|^2 = |\psi(x)|^2$$

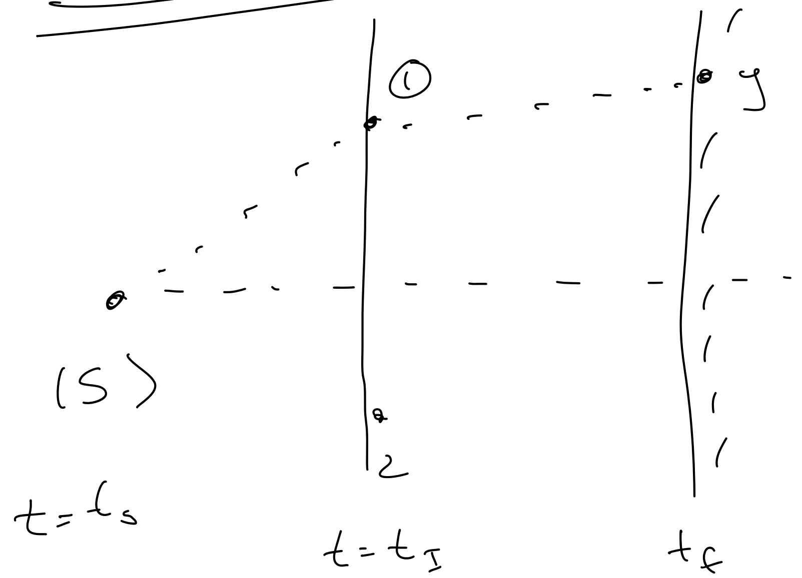
$$\langle \mathcal{O}(x,p)\rangle = \langle\psi|\mathcal{O}(x,p)|\psi\rangle$$ Skip

$$\int dx \int dx' \langle\psi|x'\rangle\langle x'|\underbrace{\mathcal{O}(x,p)}|x\rangle\langle x|\psi\rangle$$

$$\langle x'|X|x\rangle = x \qquad \langle x'|P|x\rangle = -i\frac{\partial}{\partial x}$$

x'

Double Slit



In new notation can describe series of events easily

eg $S \to 1 \to y$

$$\langle y|1\rangle\langle 1|S\rangle \equiv \psi_{①}(y)$$

Suppressing t dependence phase

Can show

$$\langle 1|2\rangle = \frac{e^{-i\vec{p}\vec{r}_{12}}}{\vec{r}_{12}}$$

if holes ① + ② symmetric

$$\langle 1|S\rangle = \langle 2|S\rangle = C$$

if only interested in cases where one makes it through the Barrier, can (re)normalize to $C = \frac{1}{\sqrt{2}}$

Now can just focus on Amplitude for state

$$|\psi\rangle_{t_I} = \frac{1}{\sqrt{2}}\left(|1\rangle + |2\rangle\right)$$

to be measured at y. $\langle y|\psi\rangle$

$$|\psi(1)\rangle = \frac{1}{\sqrt{2}}\left(|1\rangle + |2\rangle\right)$$

$$\langle y|\psi\rangle = \frac{1}{\sqrt{2}}\left(\langle y|1\rangle + \langle y|2\rangle\right) = \frac{1}{\sqrt{2}}\left(\psi_{1} + \psi_{2}\right)$$

$$P(y) = \frac{1}{2}\left(\langle y|1\rangle^2 + \langle y|2\rangle^2 + 2\sqrt{\langle y|1\rangle^2 \langle y|2\rangle^2}\cos\delta\right)$$

$$P_1 + P_2 + 2\sqrt{P_1 P_2}\cos\delta$$

phase differnce

$$\delta = \vec{p}\cdot\vec{r}_{1y} - \vec{p}\,\vec{r}_{2y}$$

$$= p\left[(\cos\theta_1 - \cos\theta_2)L + \sin\theta_1 y - \sin\theta_1 d - \sin\theta_2 y - \sin\theta_2 d\right]$$

$$= p\left[(\cos\theta_1 - \cos\theta_2)L + (\sin\theta_1 - \sin\theta_2)y - (\sin\theta_1 + \sin\theta_2)d\right]$$

If $\theta_1 \sim \theta_2 \cong \theta$

$$\delta = p\,(-2\sin\theta\, d) = -pw\sin\theta$$

($2d \to w$)

QM Predicts interference

$$\psi(y) = \psi_{1} + \psi_{2}$$

$$P(y) = |\psi_{1} + \psi_{2}|^2$$

How do we explain result when we measure the position?

$$M_y |1\rangle = d |1\rangle$$

$$M_y |2\rangle = -d |2\rangle$$

But $M_y |4\rangle \neq c |4\rangle$

Need rule ③

$$M_y\left(\frac{1}{\sqrt{2}}|1\rangle + \frac{1}{\sqrt{2}}|2\rangle\right) = \begin{cases} d\,|1\rangle & \left(\frac{1}{\sqrt{2}}\right)^2 \\ -d\,|2\rangle & \frac{1}{2} \end{cases}$$

Prob

So ...

$$\frac{1}{\sqrt{2}}\left(|1\rangle + |2\rangle\right) \xrightarrow{M_y} \begin{cases} |1\rangle & \rightarrow \langle y|1\rangle \\ \quad \text{or} & \\ |2\rangle & \rightarrow \langle y|2\rangle \end{cases}$$

just after slits

"Poof"

So will get $\langle y|1\rangle$ 50% of the

$\langle y|2\rangle$ " " "

$$P_{12} = 0.5|\langle y|1\rangle|^2 + 0.5|\langle y|2\rangle|^2$$

No interference term.

QM Predicts No interference when measuring intermediate state w/o Measmt

$$|\psi\rangle_{t_i} = \frac{1}{\sqrt{2}}\left(|1\rangle_{t_i} + |2\rangle_{t_i}\right) \xrightarrow{\text{Sch eq}} \frac{1}{\sqrt{2}}\left(|1\rangle_{t_f} + |2\rangle_{t_f}\right)$$

$$\langle y|\psi\rangle_{t_f} = \frac{1}{\sqrt{2}}\left(\langle y|1\rangle_{t_f} + \langle y|2\rangle_{t_f}\right)$$

$$P(y) = \frac{1}{2}\left(P_1^2 + P_2^2 + \text{Interference term}\right)$$

w/ Measmt

$$|\psi\rangle_{t_i} = \frac{1}{\sqrt{2}}\left(|1\rangle_{t_i} + |2\rangle_{t_i}\right) \xrightarrow{\text{Measmt}} \begin{cases} |1\rangle_{t_m} \xrightarrow{\text{Sch eq}} |1\rangle_{t_f} \\ \text{or} \\ |2\rangle_{t_m} \longrightarrow |2\rangle_{t_f} \end{cases}$$

$$\langle y|\psi\rangle_{t_f} = \begin{cases} \langle y|1\rangle_{t_f} \text{ or} \\ \langle y|2\rangle_{t_f} \end{cases}$$

$$P(y) = \begin{matrix} P_1 \text{ or} \\ P_2 \end{matrix}$$

"Orthodox" QM Axioms 1, 2 & 3

"Sch eq + Collapse"

Explains All the data

(ill-defined, don't say when Sch doesn't Apply. Doesn't say what measmt is)

Will see tomorrow. we don't need 3

-) All predictns identical to Orthodox QM

-) Well-defined! No "measurement"

-) Only have Sch Eq.

-) Price have to talk about measmts in terms of QM.

$$\langle x' | P | x \rangle = \int dp \, \langle x' | P | p \rangle \underbrace{\langle p | x \rangle}$$

$$\int dp \, e^{-ip x'} \, p \, e^{-ipx}$$

$$-i \frac{\partial}{\partial x} e^{-ipx}$$

$$-i \frac{\partial}{\partial x} \int dp \, e^{-ip(x-x')}$$

$$-i \frac{\partial}{\partial x} \delta(x-x')$$