- QM w/o wave function collapse

① $|\psi\rangle$ all there is

$\hat{O}$ Operators

② $\hat{O}|\phi\rangle = \lambda_\phi|\phi\rangle$ $\Rightarrow$ Sch. eq.

Definite value λ_ϕ

That's all! No | collapse
measurement
Probabilities

To Cover

Why does it look like the wavefunction collapses?

Where do probabilities come from?

→) Minimalist QM clearly agrees w/ O QM
when not "observing" which hole.
O-QM didn't use ③ there.

→) M-QM when measuring w/ γ

Measurements not special, QM said

$$H = H_e + H_D + H_I$$

$|``\text{Ready}"\rangle_D$ — 10^{23} atoms ground state

H_I – horribly complicated. High-level behavior simple!

Detector reports e-seen at ①

$$|``R"\rangle_D |1\rangle_e \xrightarrow[t_I]{\text{Sch eq}} |``1"\rangle_D |1\rangle_e \quad t_m$$

" ②

$$|``R"\rangle_D |2\rangle_e \xrightarrow[t_I]{\text{Sch eq}} |``2"\rangle_D |2\rangle_e$$

↳ Whole job of experimental physics is to tune H_I to get this effect!

Double Slit w/ γ

$$|\psi\rangle^{\omega}_{t_i} = |\psi\rangle_D \, |\psi\rangle_{e\,t_I}.$$

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

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

$t_i \to t_m$ (Sch E!)

$$|\psi\rangle^{\omega}_{t_m} = \frac{1}{\sqrt{2}}\left(|``1"\rangle|1\rangle + |``2"\rangle|2\rangle\right)_{t_m}$$

$\xrightarrow[\text{more Sch}]{}$ $$|\psi\rangle^{\omega}_{t_f} = \frac{1}{\sqrt{2}}\left(|``1"\rangle|1\rangle + |``2"\rangle|2\rangle\right)$$

$${}_e\langle y|\left(|\psi\rangle^{\omega}_{t_m}\right) = \frac{1}{\sqrt{2}}\left(|``1"\rangle\langle y|1\rangle_e + |``2"\rangle\langle y|1\rangle_e\right)$$

Not a #, <u>vector</u>

Need to contract w/ $|\psi\rangle_D$

Only non zero when $|``1"\rangle_D$ or $|``2"\rangle$

$$\langle ``1"| \langle y| \left( |\psi\rangle^{\omega}_{t_f} \right) = \frac{1}{\sqrt{2}} \underbrace{\langle ``1" | ``1" \rangle}_{1} \langle y|1\rangle$$

$$+ \frac{1}{\sqrt{2}} \cancel{\langle ``1" | ``2" \rangle}^{\,0} \langle y|2\rangle$$

$$\boxed{\langle ``1" | ``2" \rangle \sim e^{-N_A}}$$

$$\langle ``2"| \langle y| \left( |\psi\rangle^{\omega}_{t_f} \right) = \frac{1}{\sqrt{2}} \cancel{\langle ``2" | ``1" \rangle}^{\,0} \langle y|1\rangle$$

$$+ \frac{1}{\sqrt{2}} \underbrace{\langle ``2" | ``2" \rangle}_{1} \langle y|2\rangle$$

M-QM Predicts

$e^{-s} |\langle y|1\rangle|^2$ at detector "1"

or

$e^{-s} |\langle y|2\rangle|^2$ " " "2"

No interference!

Double Slit in general

$|``R"\rangle_D |1\rangle_e \to a|``1"\rangle|1\rangle + b|``2"\rangle|1\rangle + c|``R"\rangle|1\rangle$

~ 1 if light $\downarrow$ dim

~ 1 if λ - small & Intense

Similar for $|``R"\rangle_D|2\rangle_e \to a|``2"\rangle|2\rangle + \ldots$

Now

$$|\psi\rangle^{\omega}_{t_i} = |``R"\rangle_D |\psi\rangle_{e\, t_i} = |``R"\rangle \frac{1}{\sqrt{2}}\left(|1\rangle + |2\rangle\right)$$

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

$t_i \to t_m$ (Sch eq)

$$|\psi\rangle^{\omega}_{t_m} = \frac{1}{\sqrt{2}}\Big(a|``1"\rangle|1\rangle + b|``2"\rangle|1\rangle + c|``R"\rangle|1\rangle +$$
$$b|``1"\rangle|2\rangle + a|``2"\rangle|2\rangle + c|``R"\rangle|2\rangle\Big)$$

$\hookrightarrow |\psi\rangle^{\omega}_{t_f}$

O-QM Prediction   Now 3 outcomes

$$\langle \text{"1"} | \langle y | \Psi \rangle^{\omega}_{t_f} = \frac{1}{\sqrt{2}} \Big(a \langle y | 1 \rangle + b \langle y | 2 \rangle \Big)$$

$$\langle_D \text{"2"} | \langle_e y | \Psi \rangle^{\omega}_{t_f} = \frac{1}{\sqrt{2}} \Big(b \langle y | 1 \rangle + a \langle y | 2 \rangle \Big)$$

if $a \sim 1$ $b \sim 0$ No interference

if $a \sim b$ => "Bad detector"

get interference

$$\langle \text{"R"} | \langle y_e | \Psi^{\omega} \rangle = \frac{1}{\sqrt{2}} \Big(c \langle y | 1 \rangle + c \langle y | 2 \rangle \Big)$$

Always get interference if Detector doesn't go off!

O-QM vs M-QM

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

$$|\psi\rangle^{\omega} = \frac{1}{\sqrt{2}}\left(|``1"\rangle|1\rangle + \cancel{|``2"\rangle|2\rangle}\right)$$

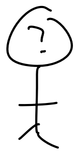
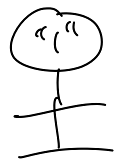
Axiom 3

or

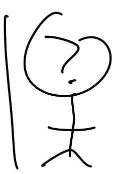
$$|\psi\rangle^{\omega} = \frac{1}{\sqrt{2}}\left(\cancel{|``1"\rangle|1\rangle} + |``2"\rangle|2\rangle\right)$$

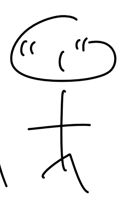
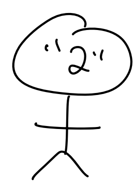
Why does it look like the wavefunction collapses?

You are a quantum mechanical system

$|$  $\rangle\,|\text{"1"}\rangle \to |$  $\rangle\,|\text{"1"}\rangle$

$$|\psi\rangle^{\omega} = |\psi\rangle_{you}\,|\psi\rangle_{D}\,|\psi\rangle_{e}$$

$= |$  $\rangle\,|\text{"R"}\rangle_{D}\,|\psi\rangle_{e}$

$= \frac{1}{\sqrt{2}}\Big(|$  $\rangle\,|\text{"1"}\rangle\,|1\rangle + |$  $\rangle\,|\text{"2"}\rangle\,|2\rangle\Big)$

Both people "see" ψ collapse, one to $|1\rangle$
one to $|2\rangle$

Looks like Ψ collapses because you are part of the system

Note also

$$= \frac{1}{\sqrt{2}}\Big(\big|\text{“1”}\big\rangle \big|\text{“1”}\big\rangle |1\rangle_e + \big|\text{“2”}\big\rangle \big|\text{“2”}\big\rangle |2\rangle_e \Big)$$

"you" tangible e "atoms"

Not accessible! Shadow e "atoms"

Separate "Branches" Behave as if "Worlds"

Only impact via interface, Need All other DoF to be identical.

Whence Probabilities?

Probabilities + Wavefunct collapse is an illusion caused by viewing the system from within.