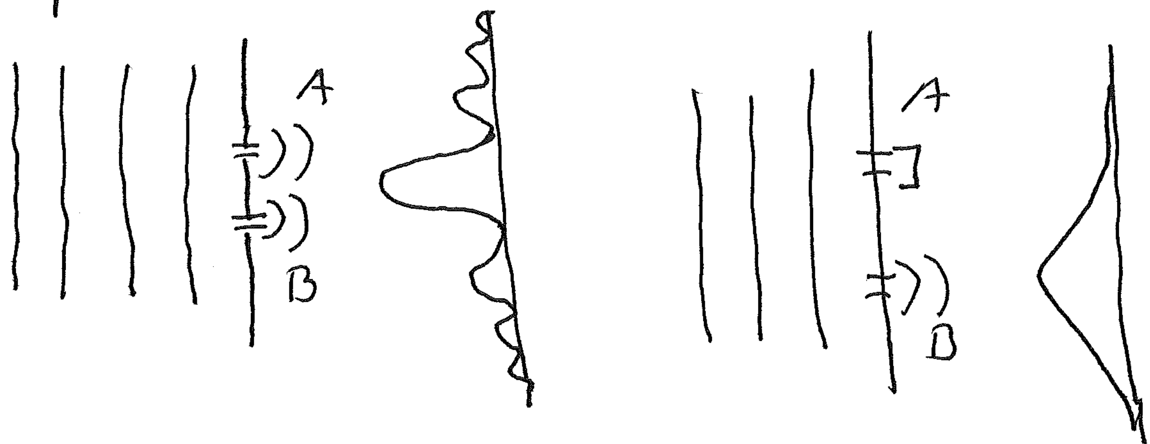
9.3 Quantum Eraser

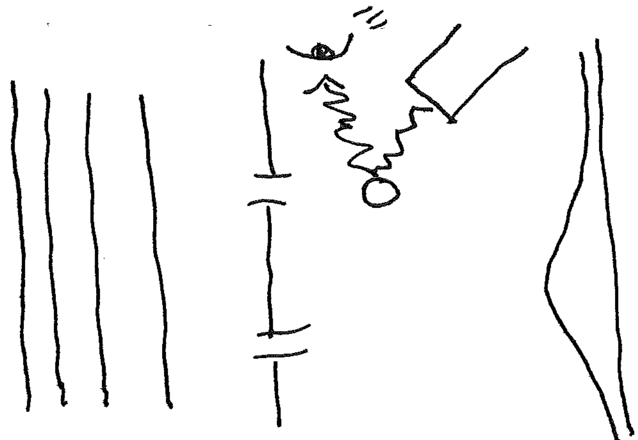
Two slit Diffraction and Copenhagen Int. of QM.



IF YOU BLOCK ONE SLIT A THEN YOU KNOW "WHICH PATH" THE PARTICLE TOOK B AND INTERFERENCE DISAPPEARS.

BOHR: "WE CAN NOT DO AN EXP. THAT SHOWS BOTH WAVE AND PARTICLE SIMULTANEOUSLY"

HEISENBERG MICROSCOPE



TO SEE WHICH SLIT IT GOES THROUGH MUST SHINE A PHOTON ON IT

$\Delta p = \hbar \Delta k$

$\Delta p \Delta x \gtrsim \hbar$

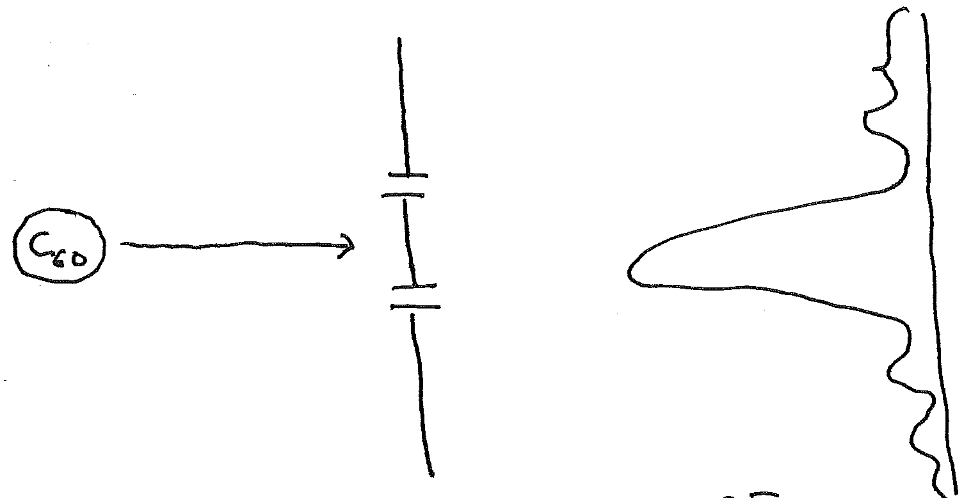
$\lambda \to 0 \quad k \to \infty \quad \Delta k \to \infty$

THE RECOIL OF PARTICLE CAUSES Δp TO BE LARGE AND SCRAMBLE INTERFERENCE

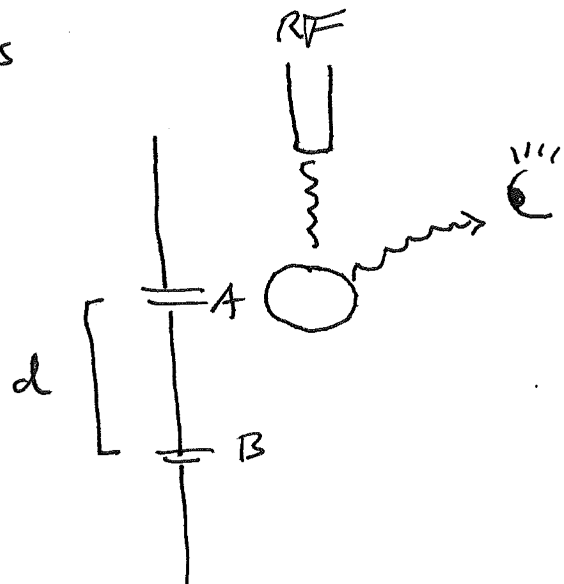
HEISENBERG UNCERTAINTY <u>ENFORCES</u> COPENHAGEN COMPLIMENTARITY.

NEITHER STATEMENT IS TRUE! CAN SEE BOTH PARTICLE & WAVE IN SINGLE EXP. AND NO H.U.P. NEEDED TO ENFORCE COMPLEMENTARITY

ZEILINGER'S BUCKY BALL EXP. C_{60} HAS A HUGE ATOMIC MASS



THEY TURN ON A WEAK RF ~~IR LASER~~ TO HEAT THE BALLS



THE WAVE LENGTH $\lambda_{RF} >> d$ SO NO WHICH PATH. AS BALL HEATS UP EMITS <u>THERMAL</u> PHOTONS λ_{TH} S.T. $k_B T = \hbar\omega_{TH}$

INITIALLY $k_B T = \hbar \omega_{TH} = \hbar c k_{TH} = \frac{2\pi\hbar c}{\lambda_{Th}}$

IF $T \approx 0°K$ $\quad \lambda_{TH} = \frac{hc}{k_B T} >> d$ and

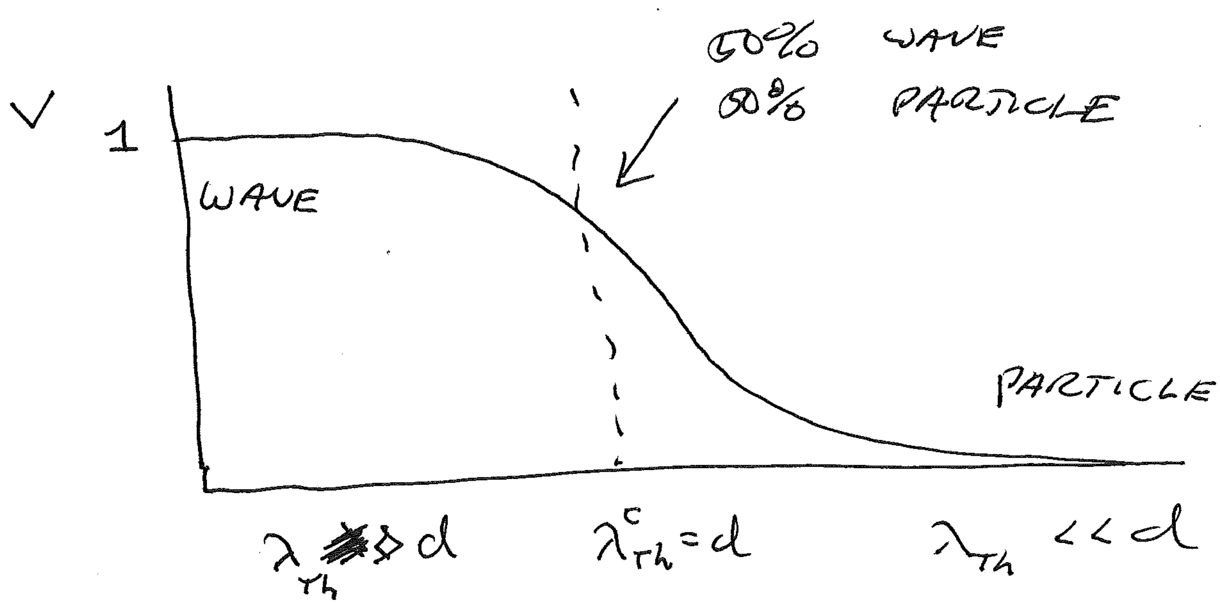
no which path. However as they crank up the temperature VISIBILITY OF FRINGES STARTS TO DROP AT T_c

$$\lambda^c_{TH} = \frac{\hbar c}{k_B T_c} = d$$

THAT IS BB EMITS PHOTONS WHOSE λ IS SHORT ENOUGH TO START TO TELL WHICH PATH. BUT

$$V = \frac{I_{MAX} - I_{MIN}}{I_{MAX} + I_{MIN}}$$

DOES NOT DROP INSTANTLY!



SO SINGLE EXPERIMENT AT $T_c = \frac{hc}{k_B d}$

GIVES BOTH WAVE & PARTICLE

$$V^2 + wp^2 = 1$$

Rollover in fringe visibility and which path information. Bohr was wrong.

Also $\lambda^c_{Th} = \frac{\hbar c}{k_B d} \Rightarrow p_c^{Th} = \hbar k_c^{Th}$

$$= \frac{\hbar 2\pi}{\lambda_c^{Th}}$$

is very small photon kick since

$\lambda_c^{Th} \simeq d \simeq$ millimeters

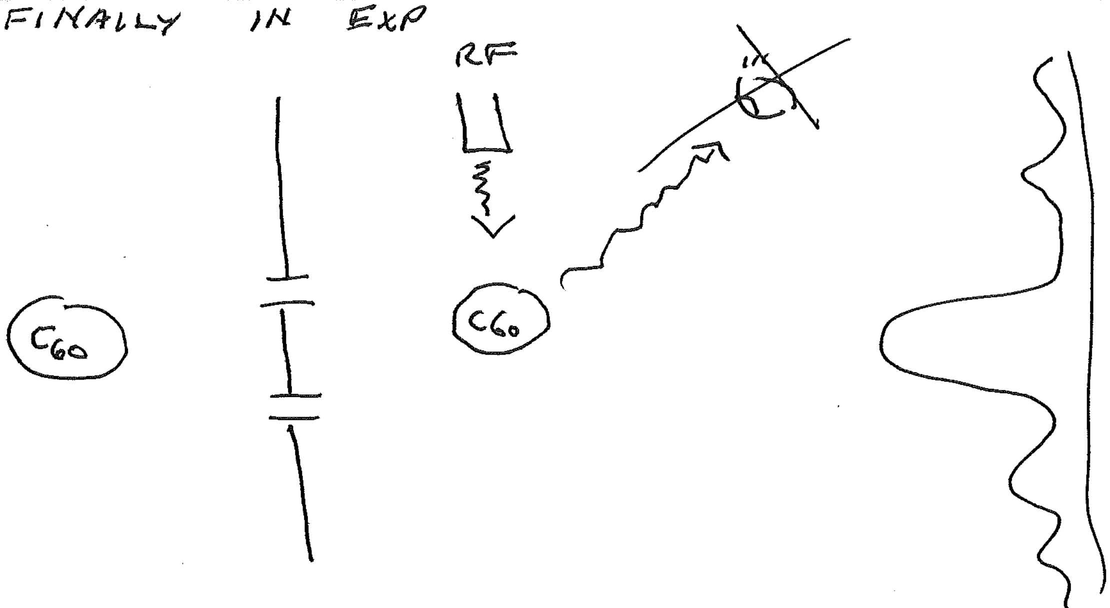
But $\underbrace{P_{BB} = \overset{\text{HUGE}}{M_{BB}} V_{BB}}_{\text{Bucky Ball}} \ggg \underbrace{p_c^{Th}}_{\text{EMITTED IR PHOTON}}$

SO RECOIL OF BUCKY BALL COMPLETELY NEGLIGABLE! NO $\Delta p \cdot \Delta x \geq \hbar$

BUSINESS HEISENBERG WRONG TOO!

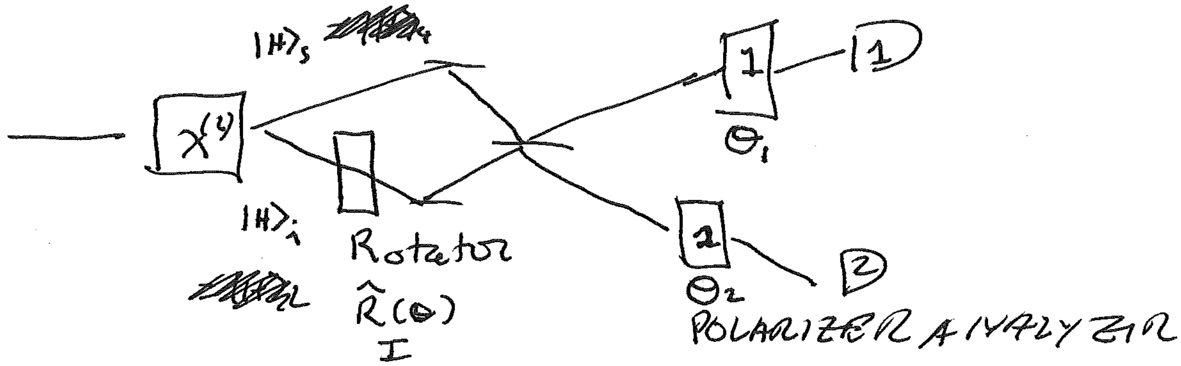
THE INTERPRETATION: WHICH PATH INFORMATION ALONE ENFORCES COMPLIMENTARITY!

FINALLY IN EXP



THEY DO NOT DETECT IR λ_{Th} PHOTONS!
HENCE IF WHICH PATH INFORMATION IS AVAILABLE — EVEN IN PRINCIPLE — FRINGES WILL VANISH.

HONG OU MANDEL Q ERASER



$$|\psi\rangle_{IN} = |H\rangle_S |H\rangle_I =$$

$$\hat{R}_I(\theta) = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}$$

$$\hat{R}_I |\psi\rangle = |H\rangle_s \hat{R}_I |H\rangle_I$$

$$= |H\rangle_s \Big[\underbrace{\cos\theta\, |H\rangle_I + \sin\theta\, |H\rangle_I}_{|\theta^+\rangle_I} \Big]$$

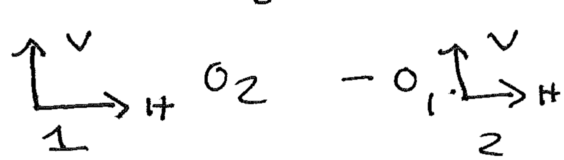
$$= \cos\theta\, |H\rangle_s |H\rangle_I + \sin\theta\, |H\rangle_s |H\rangle_I$$

$$\hat{BS}\ \hat{R}_I\, |\psi\rangle_{IN} = |\psi\rangle_{OUT}$$

$$|\psi_{OUT}\rangle = \frac{i}{\sqrt{2}} \cos\theta^{+} \overbrace{\Big[|2H\rangle_1 |0\rangle_2 + |0\rangle_1 |2H\rangle_2 \Big]}^{\text{H.O.M. DIP}}$$

$$+ \frac{1}{2} \sin\theta\, \overbrace{\Big[|H\rangle_1 |V\rangle_2 - |V\rangle_1 |H\rangle_2 \Big]}^{|\psi^-\rangle \text{ Bell Singlet}}$$

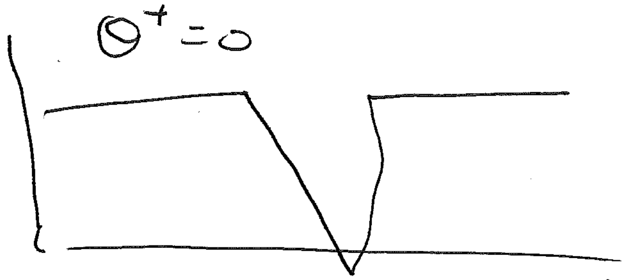
$$+ \frac{i}{2} \sin\theta\, \Big[|H,V\rangle_1 |0\rangle_2 - |0\rangle_1 |H,V_2\rangle \Big]$$



IF $\Theta^+ = 0$ THEN

$$|\Psi_{OUT}(\Theta^+=0)\rangle = \frac{i}{\sqrt{2}}\left[|2H\rangle_1|0\rangle_2 - |0\rangle_1|2H\rangle_2\right]$$

OLD <u>DIP</u> OCCURS

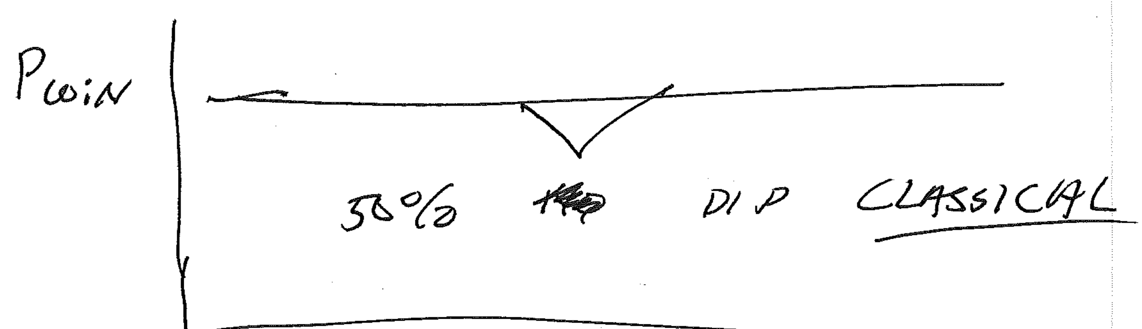


WHAT'S HAPPENING?

$$|\Psi_{OUT}(\pi/2=\Theta^+)\rangle = \frac{1}{2}\left[|H\rangle_1|V\rangle_2 - |V\rangle_1|H\rangle_2\right] + \frac{i}{2}\left[|HV\rangle_1|0\rangle_2 - |0\rangle_1|H,V\rangle_2\right]$$

THE $\hat{R}(\Theta^+)$ MARKS THE IDLER PHOTON WITH <u>WHICH PATH</u> H, V DIFFERENT MODES WHEN $|S\rangle$ $|I\rangle$ ARRIVE AT BS.

<u>DISTINGUISHALBLE</u> IN PRINCIPAL BY POLARIZATION MEAS.

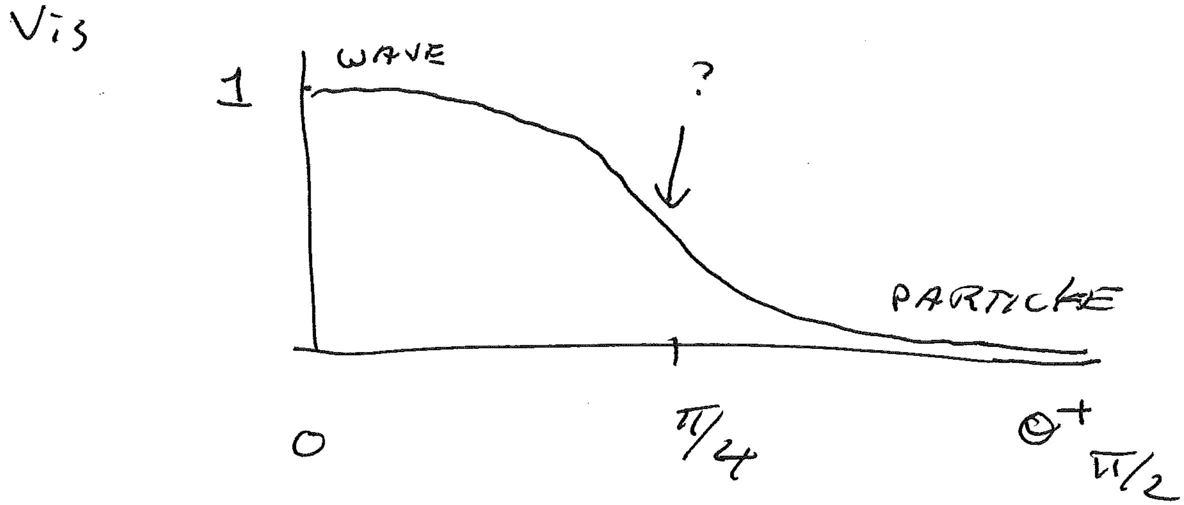


INT. ~~VANISHES~~

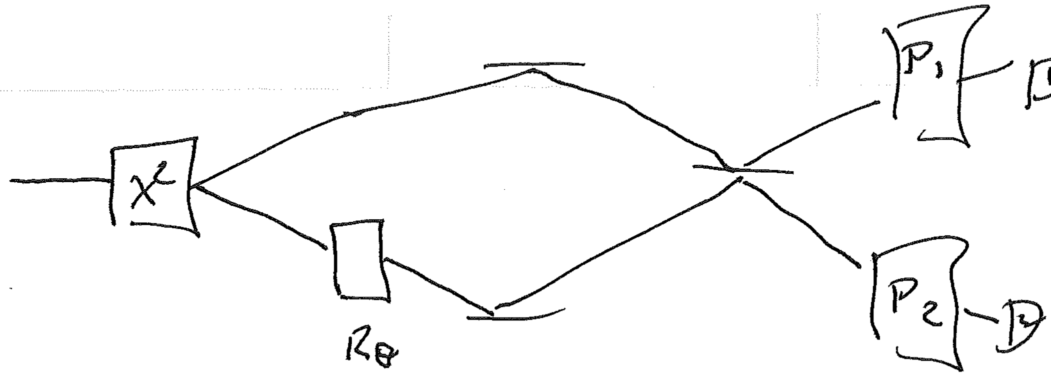
$$P_{coin}[\delta l=0] = |\langle\Psi_{OUT}|a_1^\dagger a_2^\dagger a_1 a_2|\Psi_{OUT}\rangle = 0.5$$

AS BEFORE

$$Vis = \frac{P_c^{MAX} - P_c^{MIN}}{P_c^{MAX} + P_c^{MIN}}$$



AS θ^+ INCREASES W.P. INCREASES AND VIS DROPS <u>BUT</u> <u>CONTINUOUSLY</u>



Now to erase! We place polarizers P_1 and P_2 which only allows θ_1 and θ_2

THIS PROJECTS THE 1 COMPONENT ONTO

$$|\theta_1\rangle = |H\rangle_1 \cos\theta_1 + |V\rangle_1 \cos\theta_1$$

and the 2 component onto

$$|\theta_2\rangle = |H\rangle_2 \cos\theta_2 + |V\rangle_2 \cos\theta_2$$

Let us take $|\psi\ \text{out}(\theta = \pi/2)\rangle$ which has complete which path information

$$P_{coin} = |\langle\theta_1|\langle\theta_2|\psi_{out}(\pi/2)\rangle|^2$$

$$= \frac{1}{4}\sin^2[\theta_2 - \theta_1]$$

Hence if $\theta_2 - \theta_1 = n\pi$ $\quad n = 0, 1, 2, \ldots$

$R_{coin} = 0$ and visibility $= 100\%$

SO WHICH PATH IS ERASED!