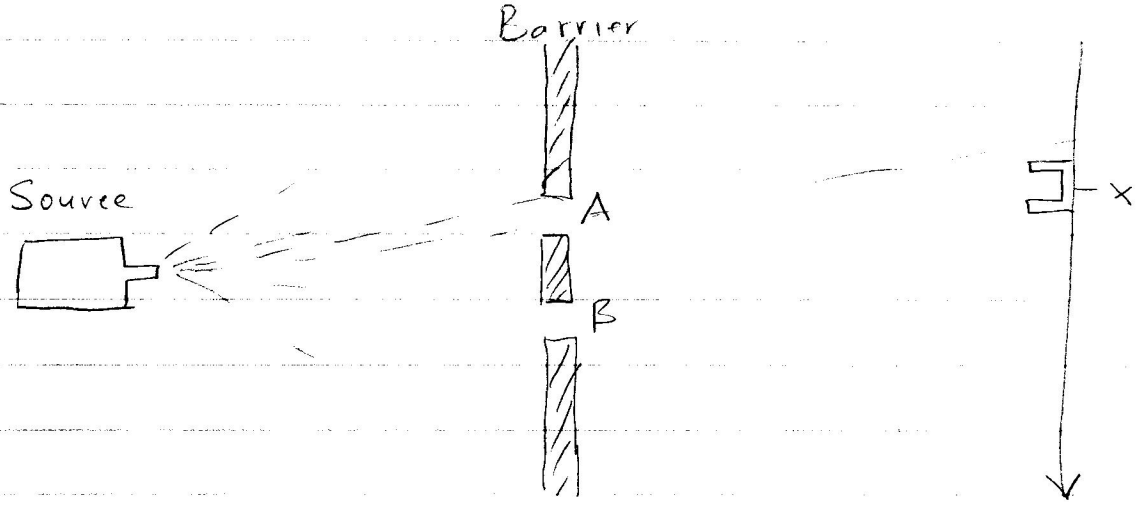
Classical Particle

particles: bullets

source: sprays bullets at constant rate
with fixed velocity
but random angles

barrier: with two hole A and B
through which bullets can pass

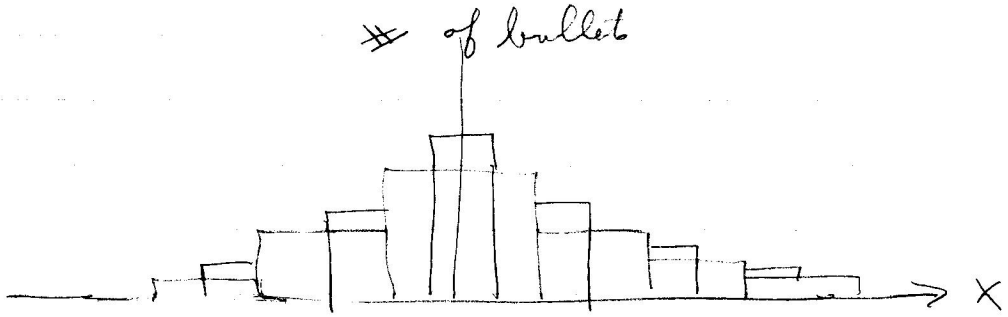
detector: absorbs bullet,
at measurable position x



- bullets are detected in discrete units (whole bullets)
- if shooting rate is decreased enough,

bullets are detected at discrete times
at discrete positions

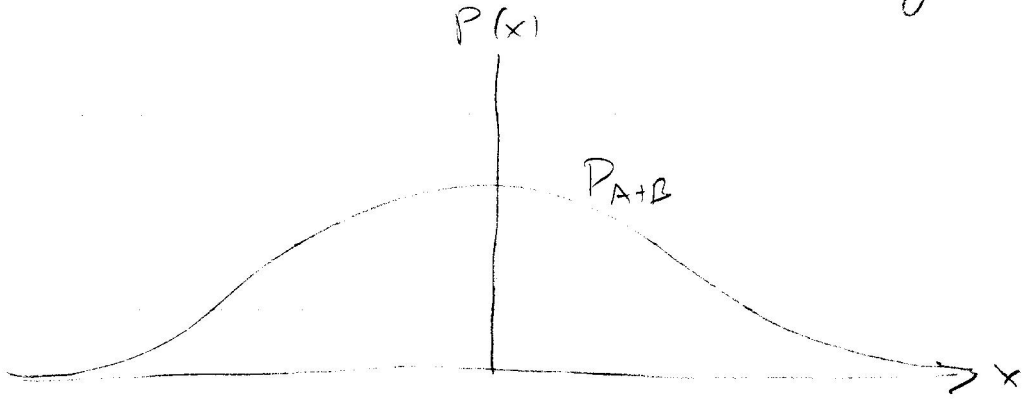
histogram: number of bullets vs. x



probability for bin $=$ $\frac{\#\text{ of bullets in bin}}{\text{total number of bullets}}$

in limits of narrow bins
many bullets

probability $P(x)$ becomes continuous function of x

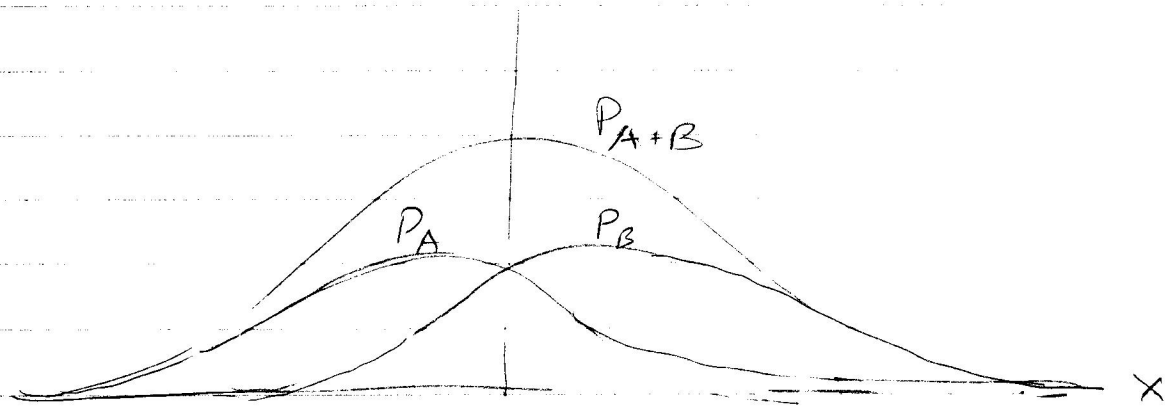


P_{A+B} = probability distribution
with both A & B and B

total probability = area under curve = 1

- each bullet that is detected passes either through A or through B

P_A = probability for bullets that pass through A



at every point x,

$$P_{A+B} = P_A + P_B$$

(no interference between A and B)

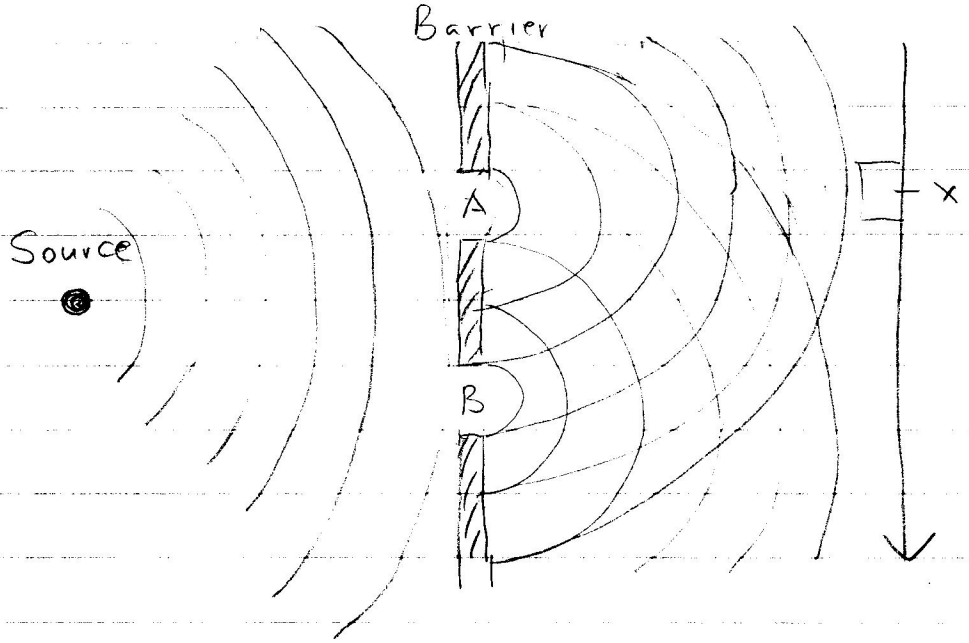
Classical Waves

waves in water

source: produces circular waves
with definite frequency ν
definite wavelength λ

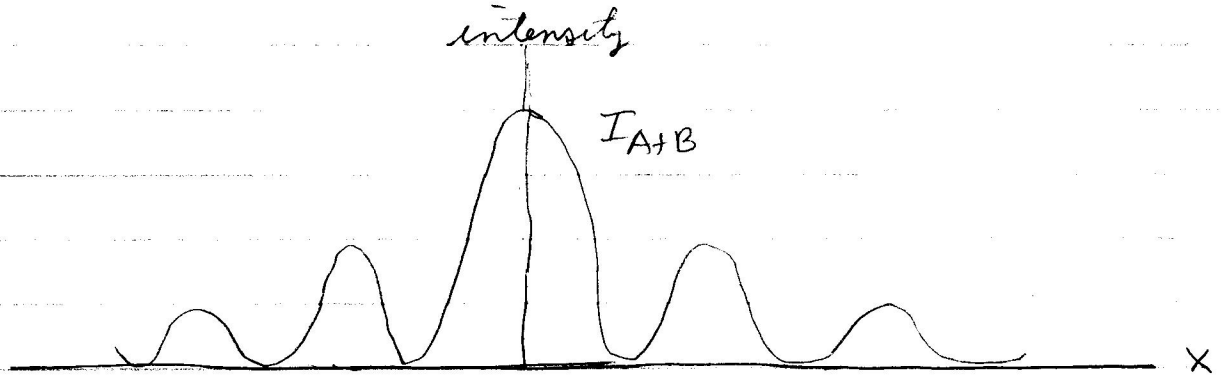
barrier: with two holes A and B

detector: measures intensity I of wave
(time average of amplitude squared: $I \propto \langle A^2 \rangle$)
as a function of position x

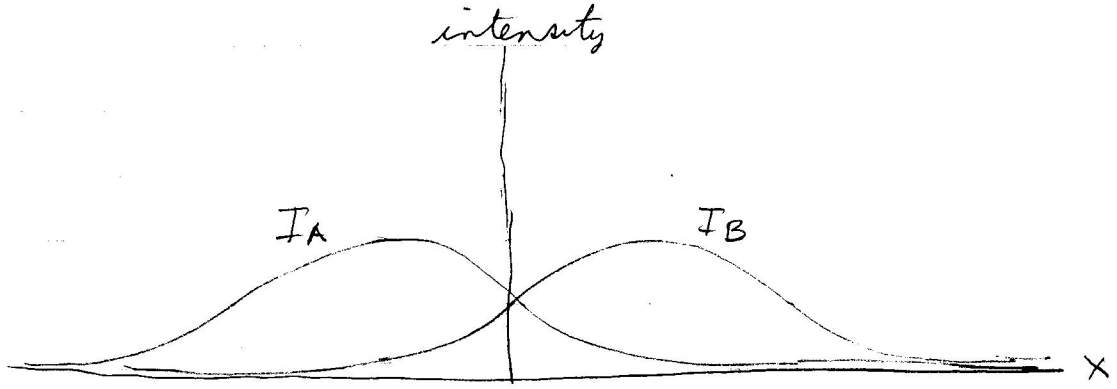


- intensity of waves is continuous variable
- detected wave has passed through both A and B

I_{A+B} : intensity distribution with both holes A and B



I_A : intensity distribution with hole A only (B is blocked)



interference : $I_{A+B} \neq I_A + I_B$

<u>A side</u> quantitative relation :

$$I_{A+B} = I_A + I_B + 2\sqrt{I_A}\sqrt{I_B}\cos\delta$$

where δ depends on x

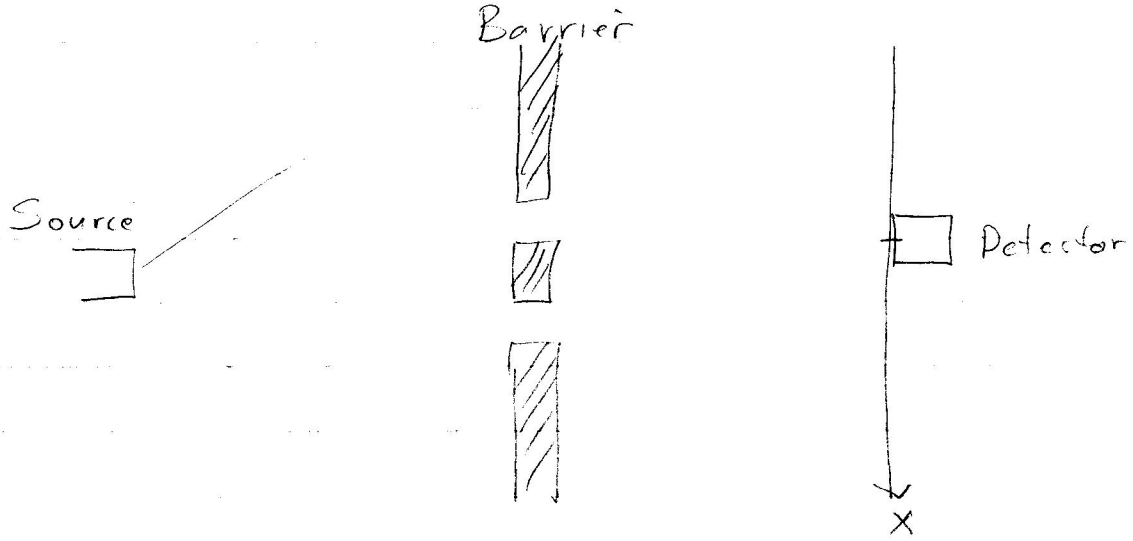
Quantum Particle/Wave

electron

source: produces electrons at same energy
with random angles

barrier: with two holes A and B

detector: signals absorption of electron



- Electrons are detected in discrete units
- If intensity of source is sufficiently low,

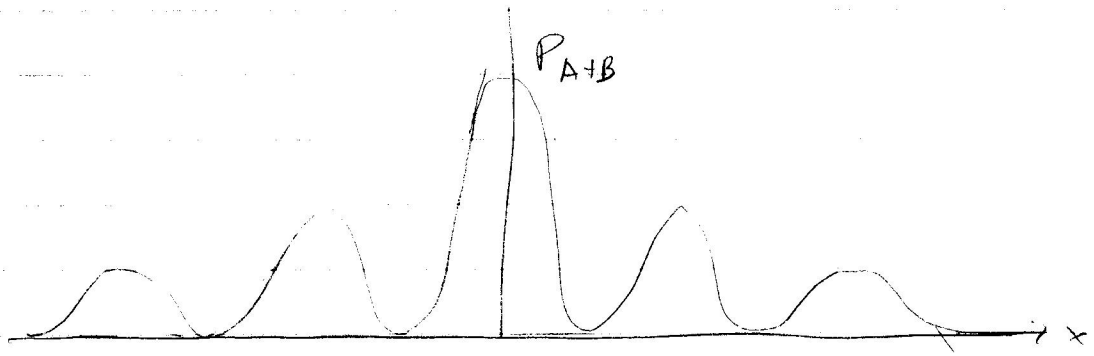
  electrons are detected at discrete time
  at discrete positions

like classical particle

- but probability distribution P_{A+B} shows interference!

like a <u>classical wave</u>

probability

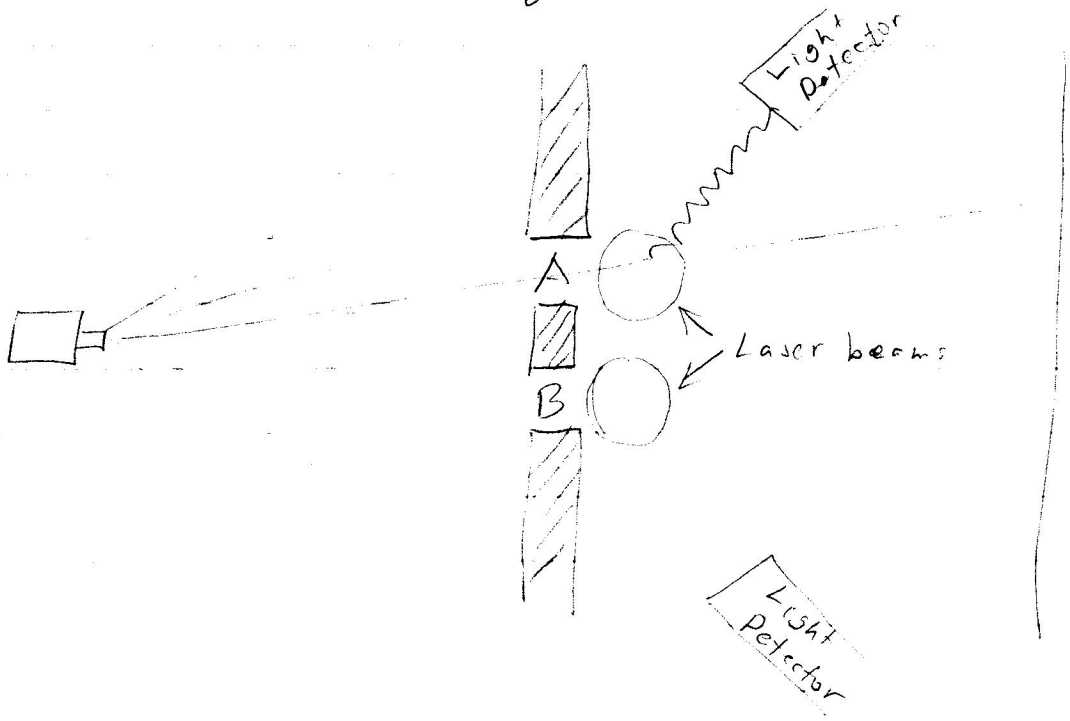


interference between
electron passing through hole A
and electron passing through hole B

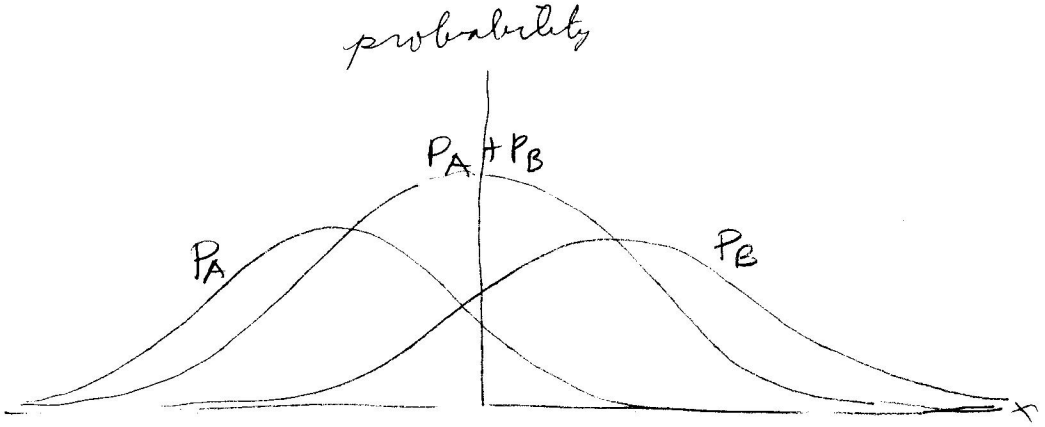
even if shooting rate is decreased
so there is only one electron at a time.

Detect hole electron goes through

laser beam in front of hole
and detector for scattered light



- Flash of light from either hole A or hole B but never both
- Probability shows no interference



Does scattering of light from laser beam disturb electron enough to destroy interference?

Decrease intensity of laser beam

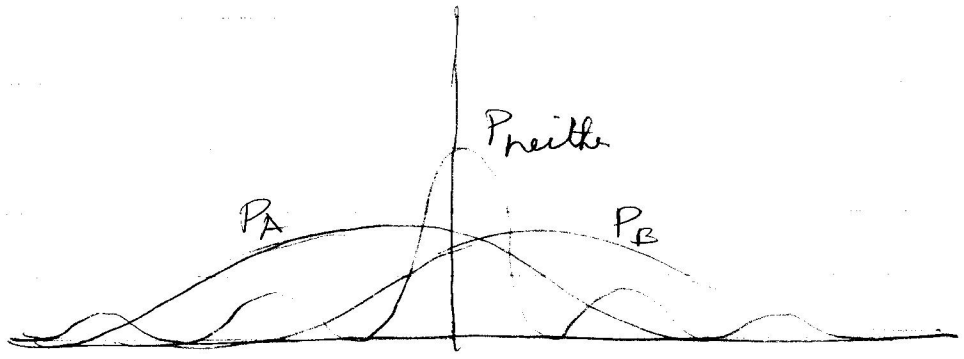
$\Longrightarrow$ flash of light has same strength but is produced less often

- light is detected in discrete units (photons)

If electron is detected, there is either

flash of light from A
flash of light from B
no flash

probabilities: P_A, P_B, $P_{neither}$



$P_{neither}$ shows interference pattern!