

Title: Enrichment Presentation on Quantum Theory - Part 2 (Session 2)

Date: Jul 11, 2006 01:00 PM

URL: <http://pirsa.org/06070020>

Abstract:

What happens when both slits are open?

- Many students think of electrons as kind of like tiny, scaled-down tennis balls (minute solid spheres).
- Given this intuition, would we pattern would we see at wall B with both slits open?
- ANSWER: (Consult with someone next to you and then draw a rough sketch.)

- Close slit 1 and open up slit 2 and we see the same pattern as before, but just shifted to the left somewhat



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probability



a)



What sort of probability pattern for electrons will we get at wall B?

probability



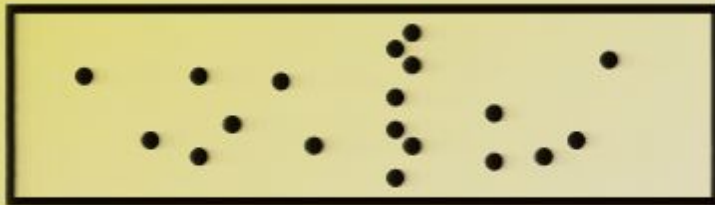
b)



probability



c)



probability



d)



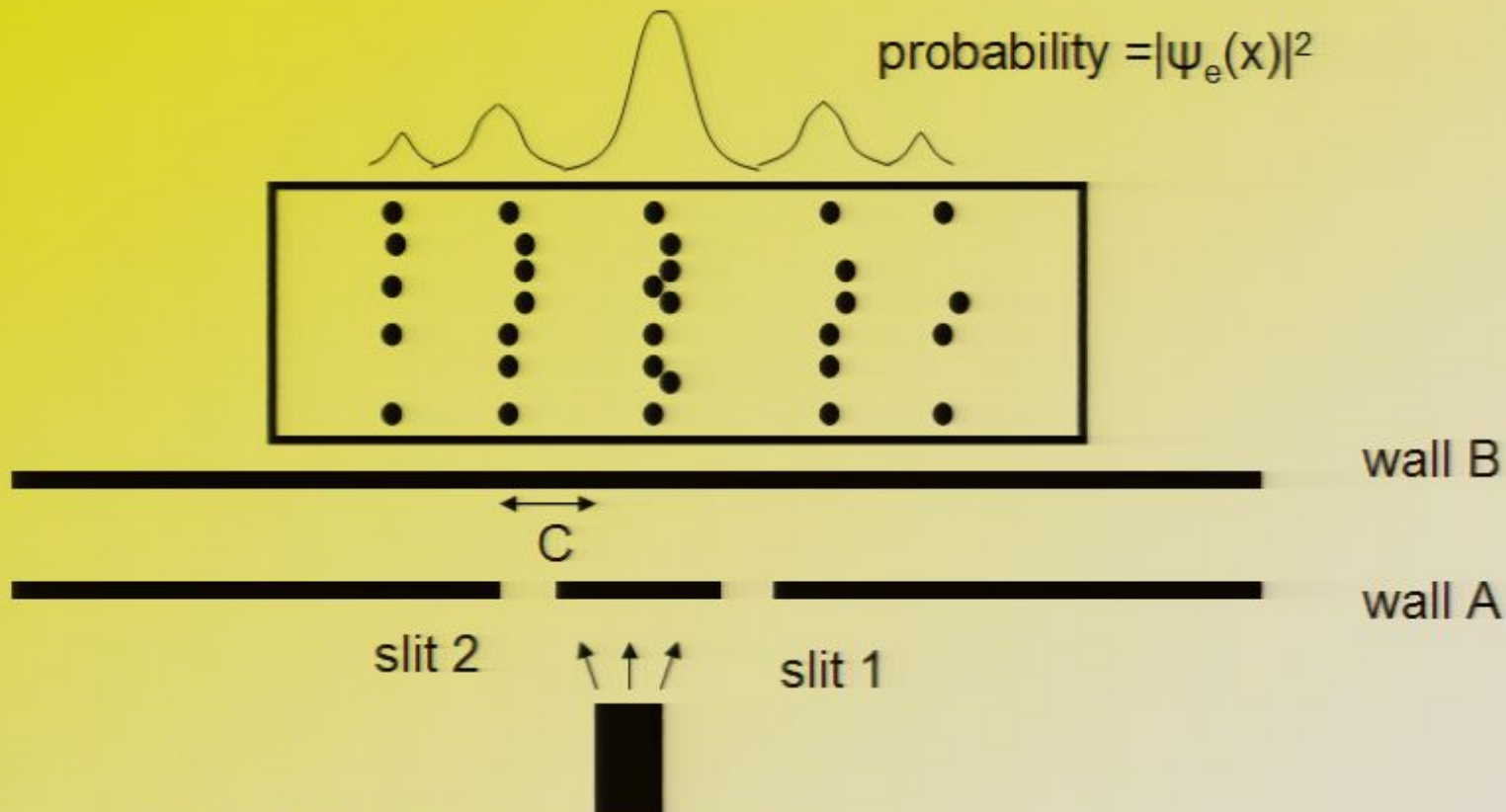
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What do we actually see?



- wave-water double-slit interference pattern
See <http://www.hqrd.hitachi.co.jp/em/movie/doubleslite.mpeg> for a video illustrating how the pattern builds up
- What happened?
- Particle model fails.
- Electrons are not like scaled-down, tiny tennis balls.

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Advances in Research

Electron phase microscopy

Movies

(1) Cobalt smoke particle observed by electron interference microscopy.



- [WMV](#) triangle.wmv (2.2M byte) 11sec.
- [MPEG](#) triangle.mpeg (1.8M byte) 11sec.

(2) Single electron events build up to form an interference pattern in the double-slit experiments.

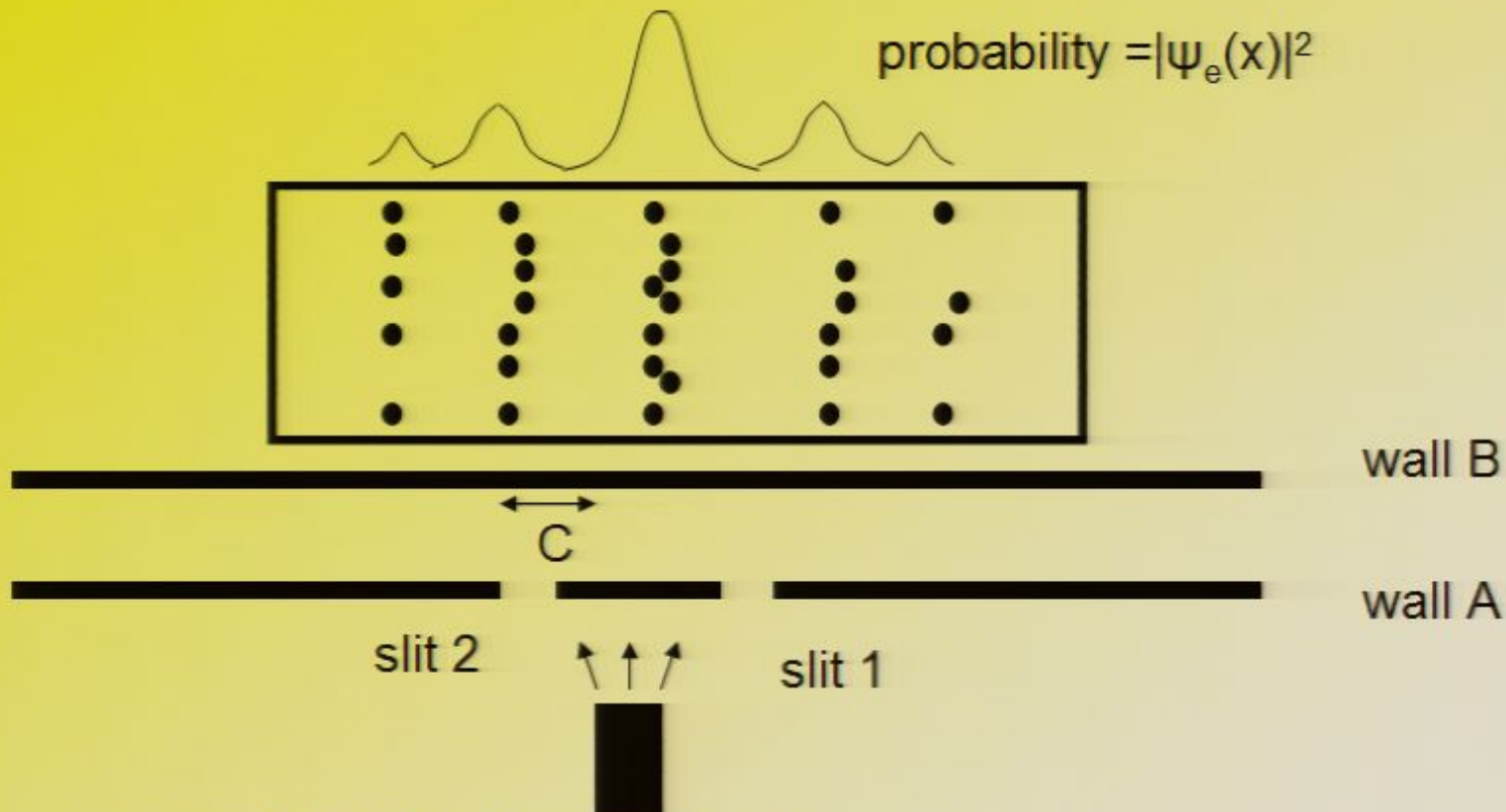


- [WMV](#) doubleslite.wmv (3.6M byte) 1min.8sec.
- [MPEG](#) doubleslite.mpeg (8.4M byte) 1min.8sec.
- with Narration
- [WMV](#) doubleslite-n.wmv (3.9M byte) 1min.8sec.
- [MPEG](#) doubleslite-n.mpeg (10.4M byte) 1min.8sec.

Quantitative example

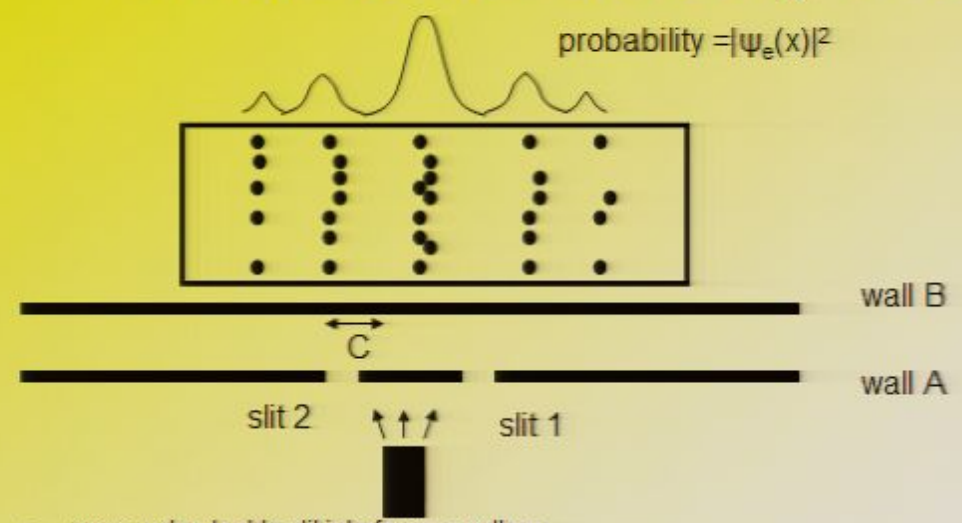
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<http://www.colorado.edu/phvsics/pnet/web-pages/simulations-base.html>

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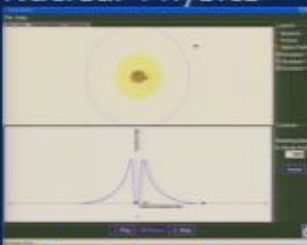
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

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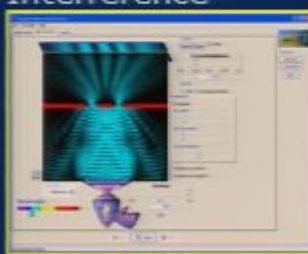
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
Nuclear Physics



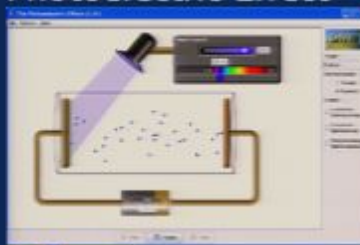
  



Quantum Wave Interference




 

Photoelectric Effect



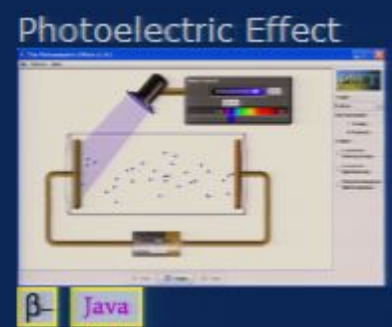
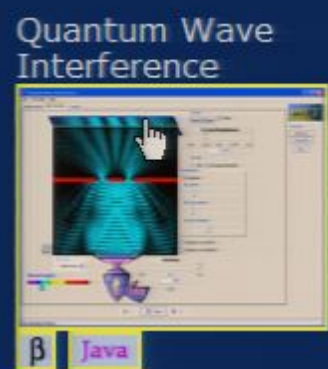
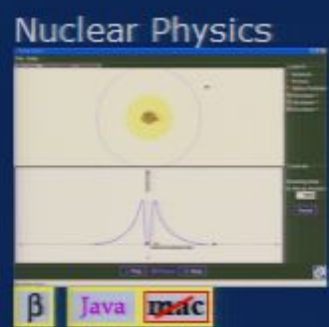
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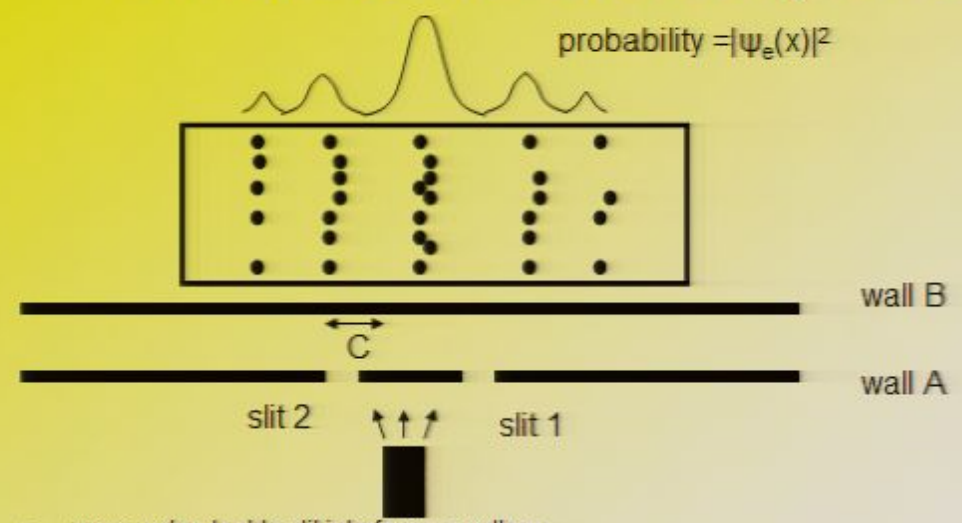
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Quantum Wave Interference: When do photons, electrons, and atoms behave like particles and when do they behave like waves? Watch waves spread out and interfere as they pass through a double slit, then get detected on a screen as a tiny dot. Use quantum detectors to explore how measurements change the waves and the patterns they produce on the screen.



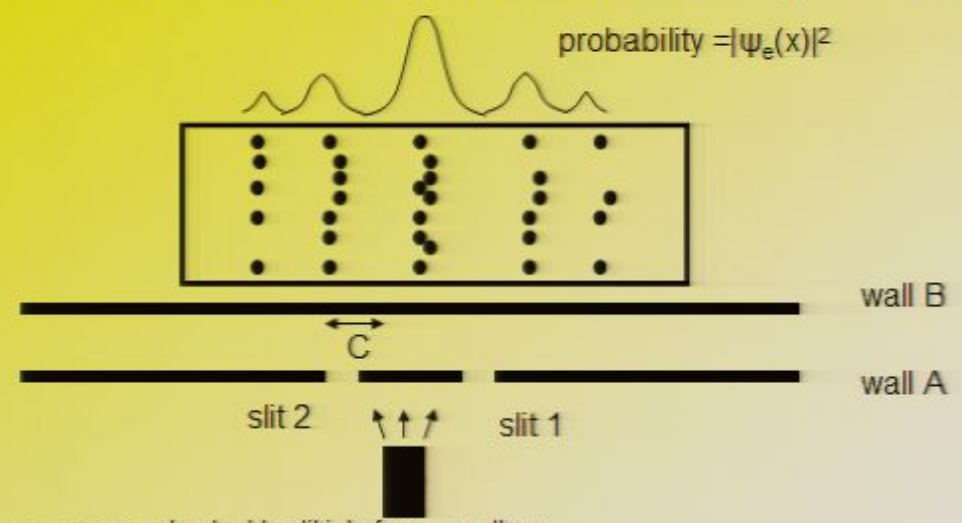
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Lasers: Create a laser by pumping the chamber with a photon beam. Manage the energy states of the laser's atoms to control its output.

Nuclear Physics

Quantum Wave Interference

Photoelectric Effect

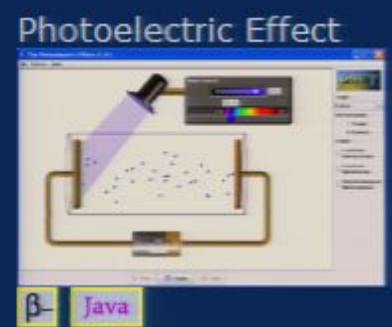
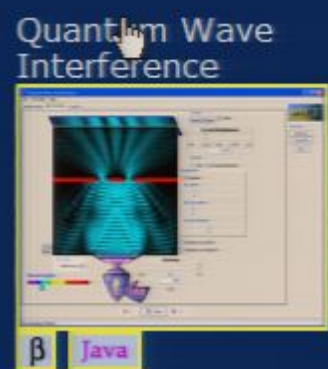
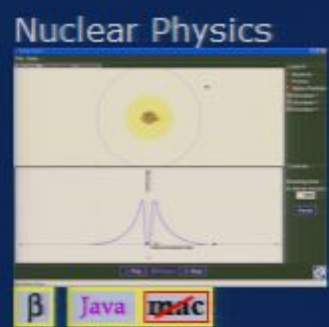
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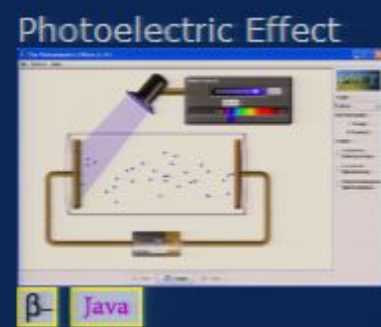
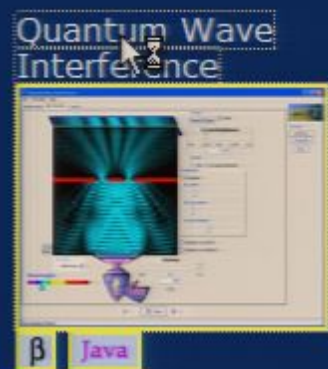
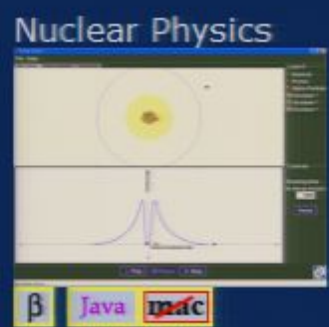
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Open with: Java(TM) Web Start Launcher (defa... ▼



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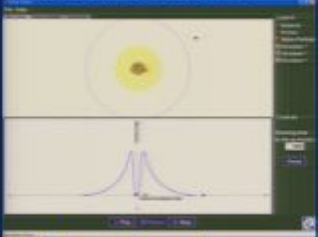
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

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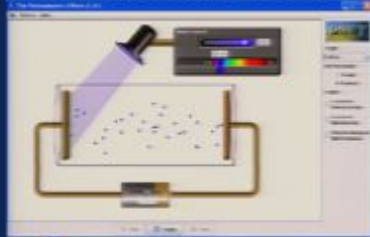
  



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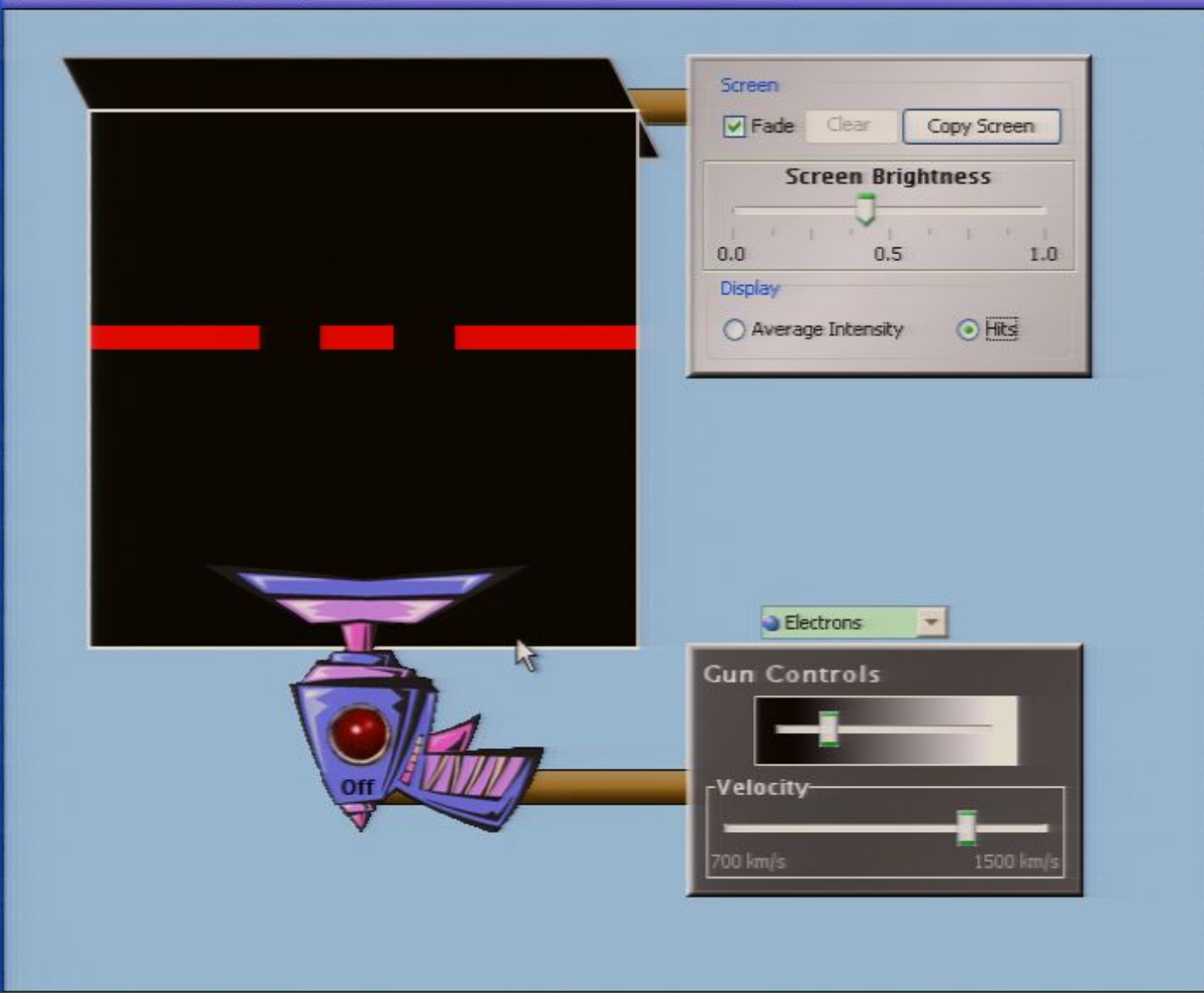


Photoelectric Effect





Screen

Fade Clear Copy Screen

Screen Brightness

0.0 0.5 1.0

Display

Average Intensity Hits

Electrons

Gun Controls

Velocity

700 km/s 1500 km/s

Ruler

Stopwatch

Reset

Clear Wave

Wave Function Display

Magnitude

Real Part

Imaginary Part

Phase Color

Disable Slits<<

Absorbing Barriers

Slit Width

Slit Separation

Vertical Position

Detector on Left Slit

Detector on Right Slit

Anti-Slits

Potential Barriers>>

Play Pause Step



Screen

Fade

Screen Brightness

0.0 0.5 1.0

Display

Average Intensity Hits

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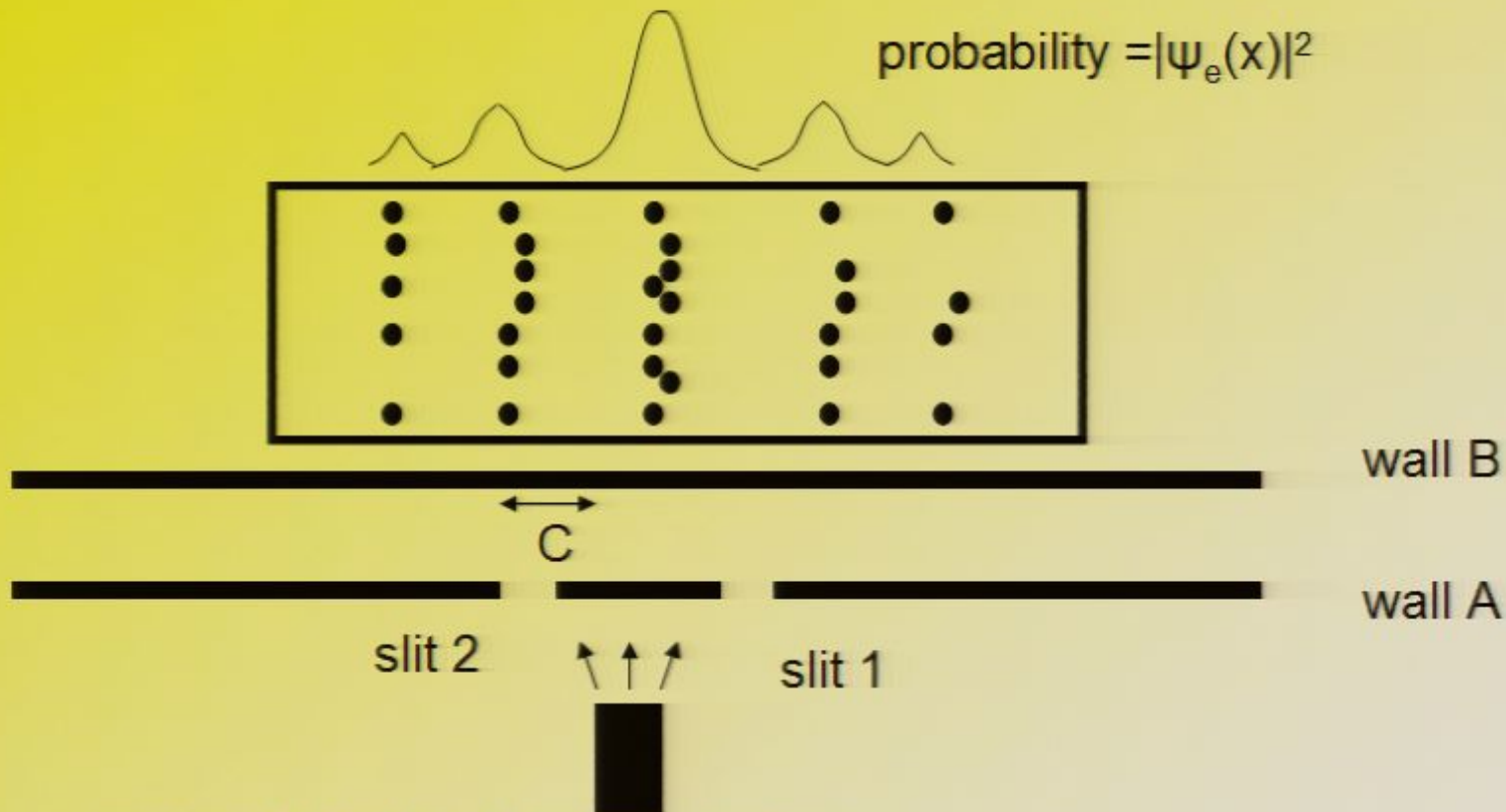
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Quantitative example

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- Assume that we detect 100 electrons at C.
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- Open both slits 1 and 2 and fire 2,000 electrons at wall A (in exactly the same manner as for the two cases above)
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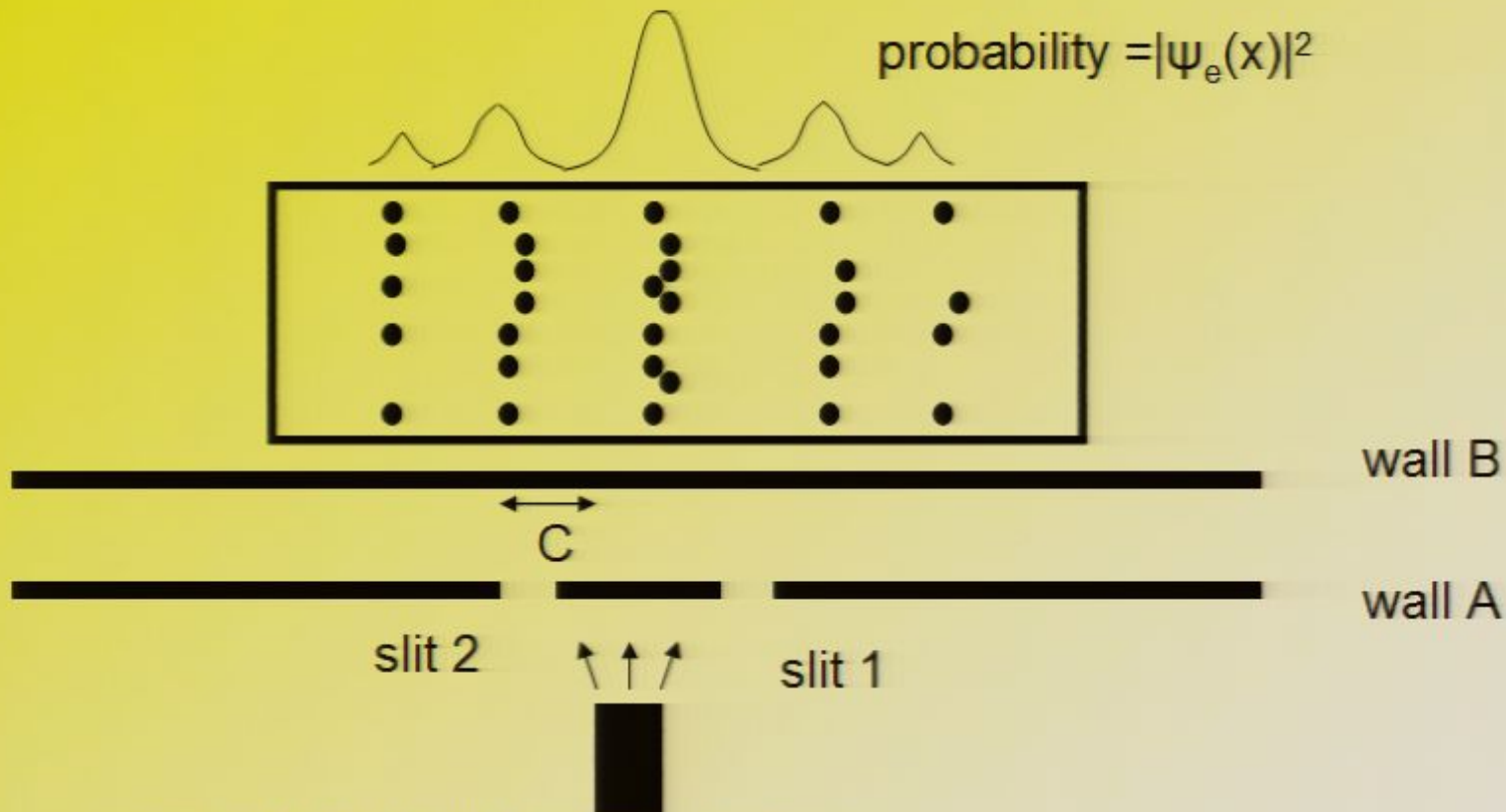


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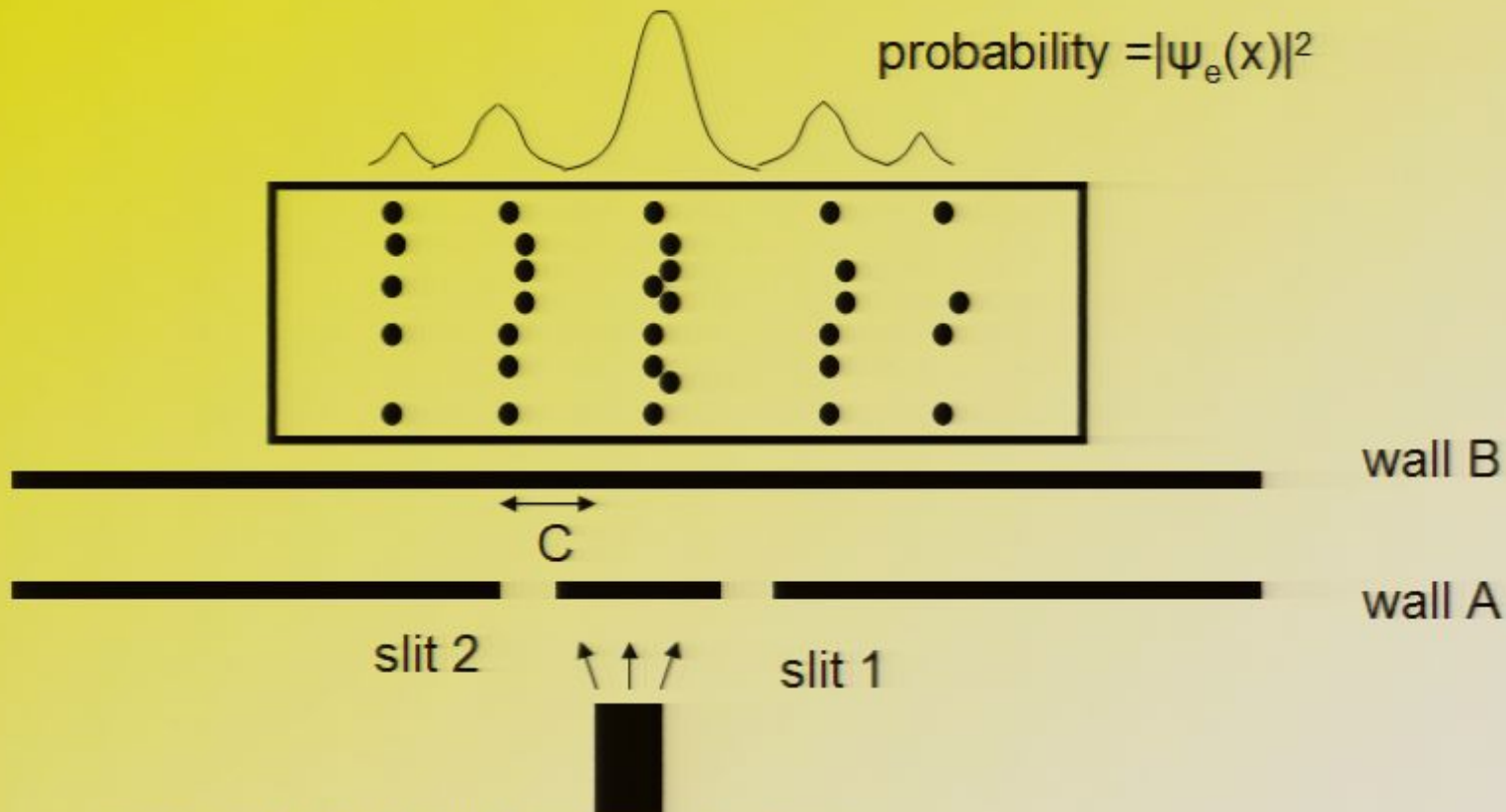


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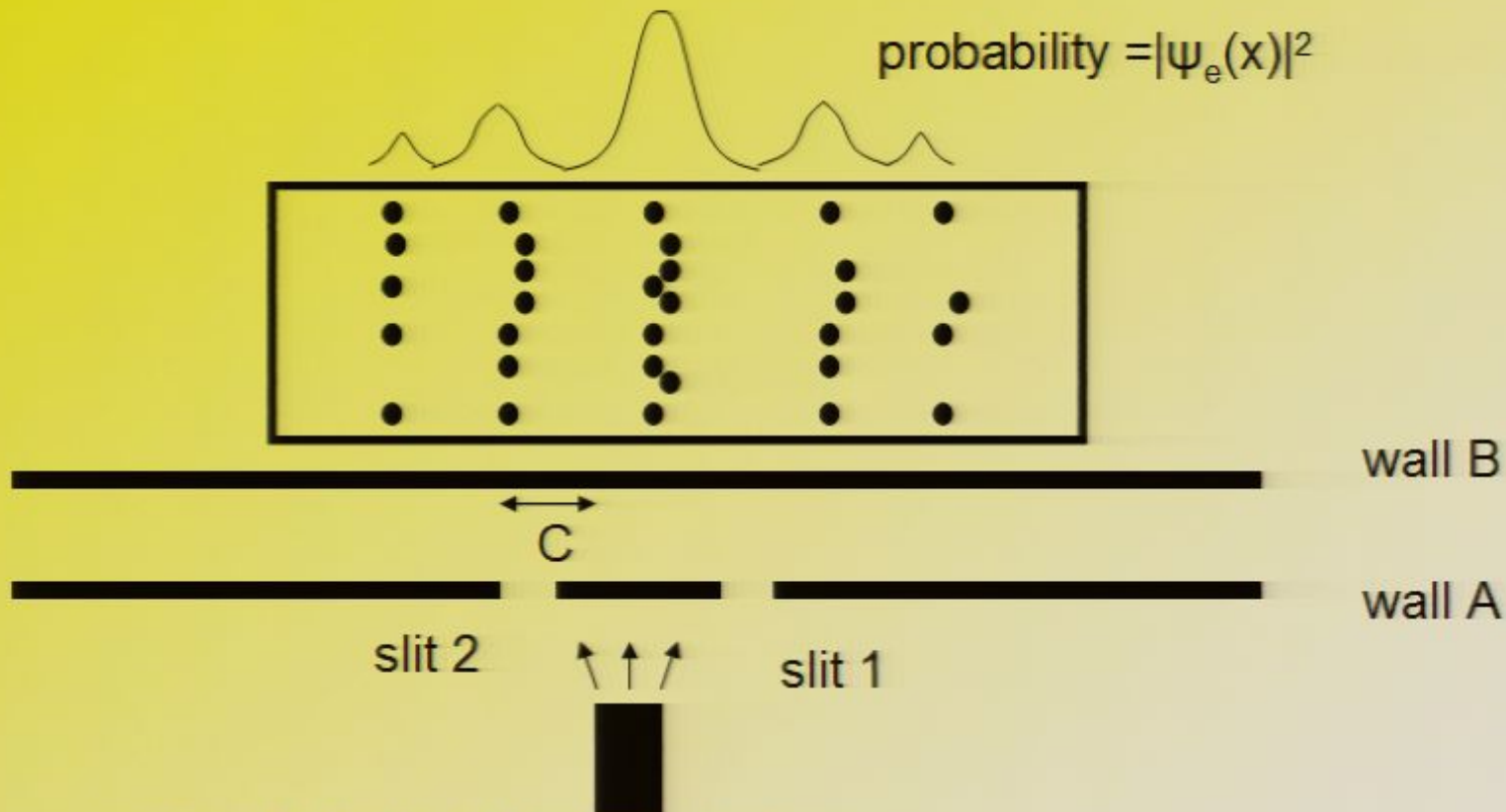


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- Can open a second slit and *decrease* the number of electrons detected at C.
- Makes no sense within the particle model.
- Probability (slits 1 & 2 open) (x) < Probability (slit 1 open) (x) + Probability (slit 2 open) (x),
where the probabilities relate to the likelihoods of finding particles at position x.

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- To calculate Probability (slits 1 & 2 open) (x), we do the same thing as for ordinary water waves:

Add the two contributing amplitudes, find the magnitude of the resulting sum and then square this.

Probability (slits 1 & 2 open) (x)

$$= |\psi_e(x)|^2$$

$$= |\psi_e^{\text{slit 1}}(x) + \psi_e^{\text{slit 2}}(x)|^2,$$

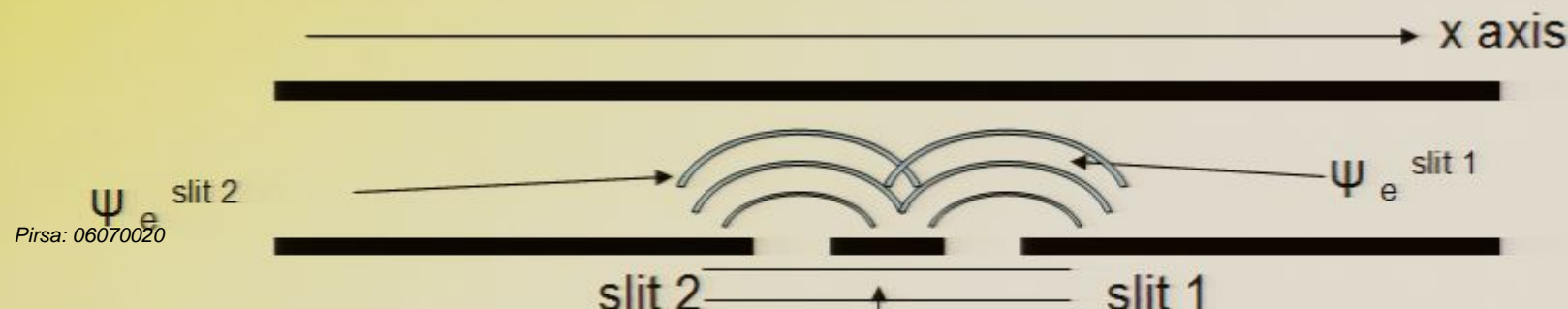
where $\psi_e^{\text{slit 1}}(x)$ and $\psi_e^{\text{slit 2}}(x)$ are wavefunctions* for electrons passing through slits 1 and 2

(Strictly speaking, we are dealing with probability densities rather than probabilities.)

•Assuming ψ_e is normalized,

$\psi_e^{\text{slit 1}}(x)$ and $\psi_e^{\text{slit 2}}(x)$

will be unnormalized



Sometimes, $|\psi_e^{\text{slit 1}}(x) + \psi_e^{\text{slit 2}}(x)|^2 < |\psi_e^{\text{slit 1}}(x)|^2 + |\psi_e^{\text{slit 2}}(x)|^2$

sum of the two probabilities
when just one slit is open

Eg. let $\psi_e^{\text{slit 1}}(x) = 1/5$ and $\psi_e^{\text{slit 2}}(x) = -1/4$.

$$|\psi_e^{\text{slit 1}}(x) + \psi_e^{\text{slit 2}}(x)|^2 = (1/5 - 1/4)^2 = 1/400 < |1/4|^2 + |1/5|^2 = 41/400$$

Destructive interference: explains why we can detect fewer electrons with both slits open

Can also get constructive interference, just as with water waves

- General rule in quantum theory is that if there are two (or more) ways of detecting a particle at some particular point AND there is no way to distinguish between them, then we add up the probability amplitudes (i.e. ψ 's) associated with these possibilities first & then find the square of the magnitude of the resulting sum to get the overall probability.

- $$\text{Prob} = | \psi_1 + \psi_2 + \psi_3 + \dots |^2$$

Activity

- Assume that at point Y , $\psi_e^{\text{slit 1}}(x=Y) = 1/10$ and $\psi_e^{\text{slit 2}}(x=Y) = 1/5$.
- What is the probability (density) $|\psi(x=Y)|^2$ of detecting the electron at Y when just slit 1 is open? i.e. $|\psi_e^{\text{slit 1}}(x=Y)|^2 = ?$
- When just slit 2 is open?
- When both slits are open?
- Is $|\psi_e^{\text{slit 1}}(x) + \psi_e^{\text{slit 2}}(x)|^2 < |\psi_e^{\text{slit 1}}(x)|^2 + |\psi_e^{\text{slit 2}}(x)|^2$ in this case?

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