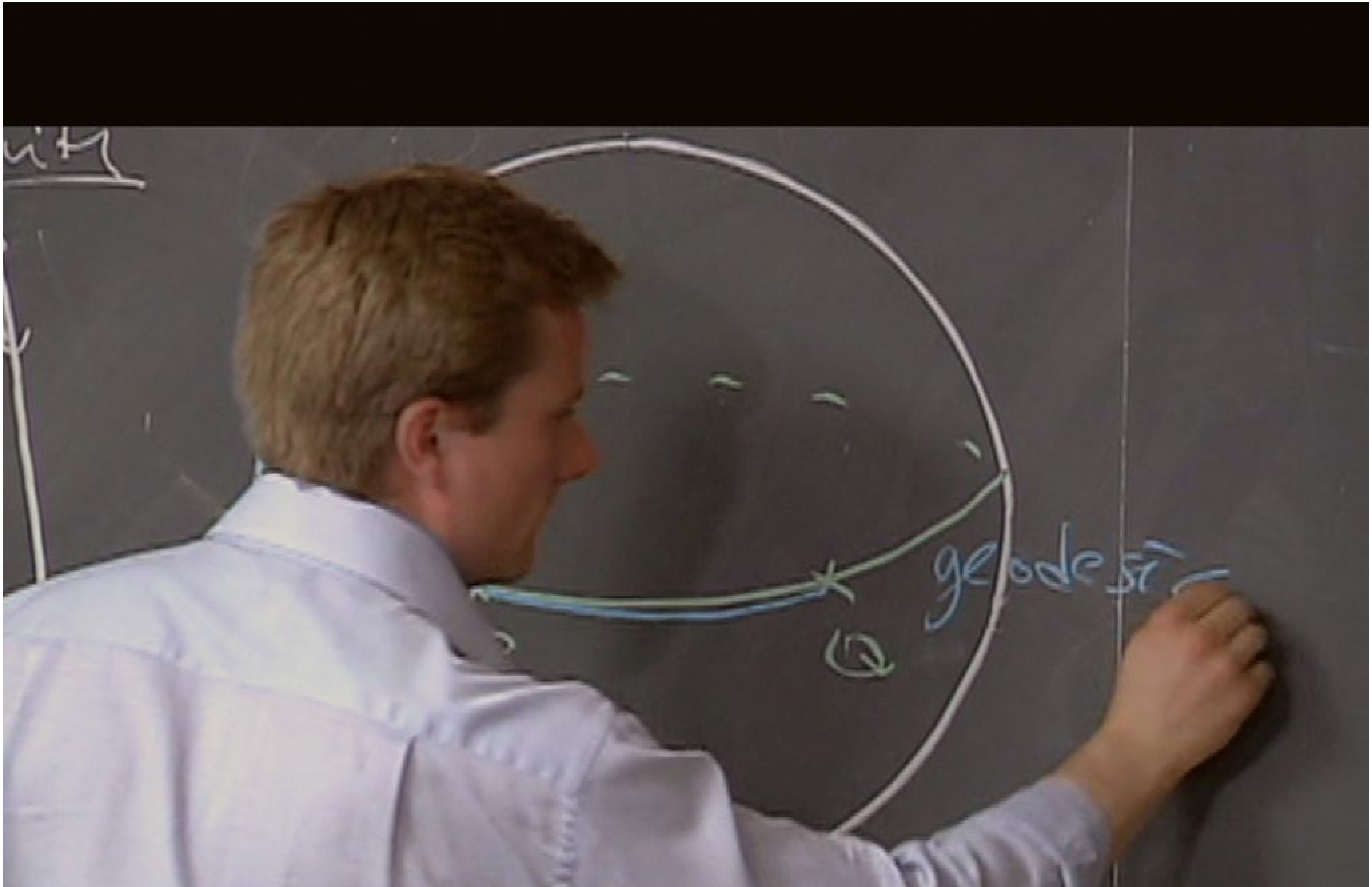
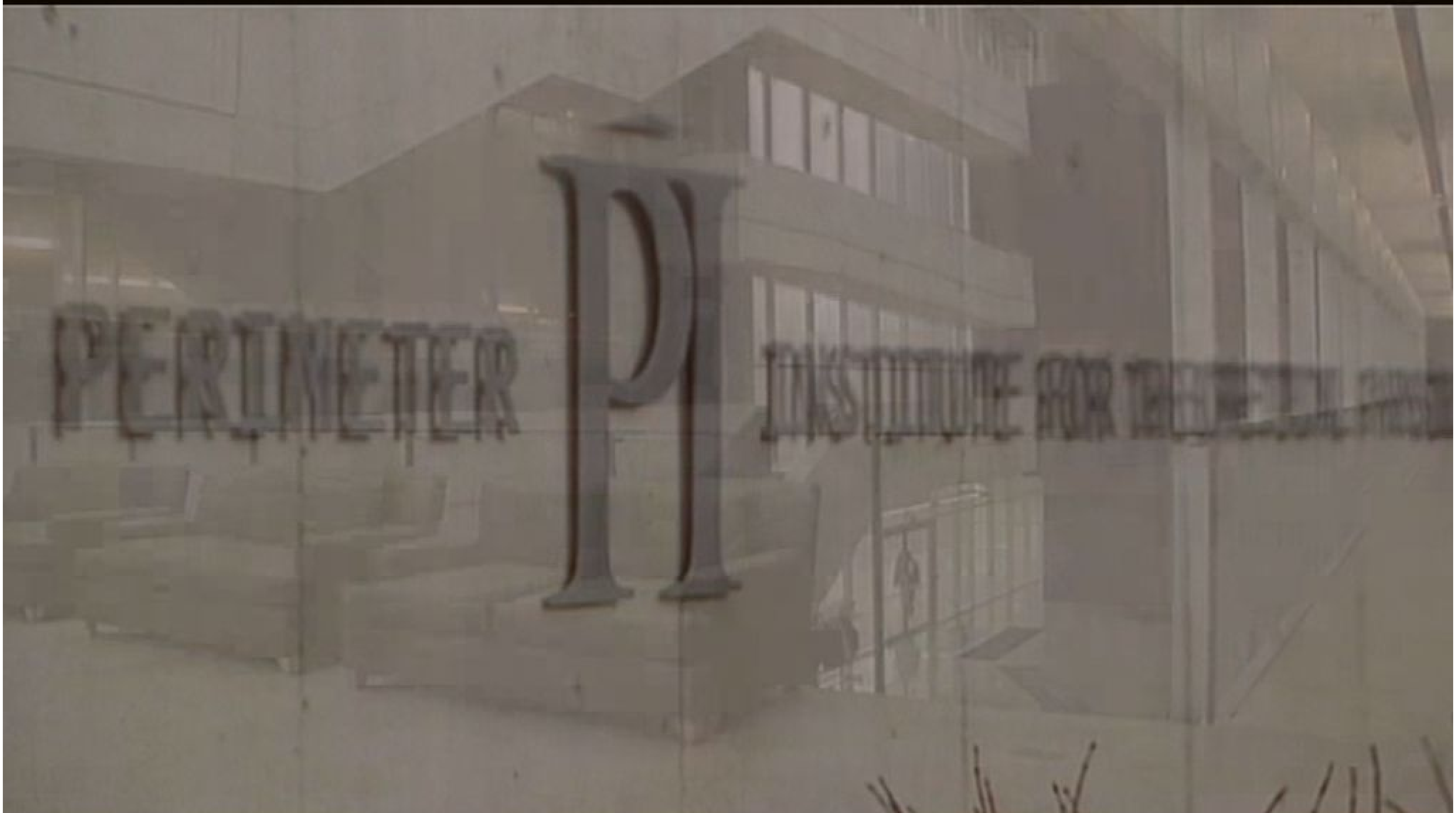
Title: Enrichment Presentation on Quantum Theory

Date: Jul 04, 2006 09:00 AM

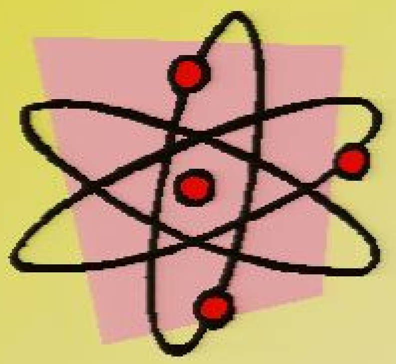
URL: http://pirsa.org/06070000

Abstract:




PERIMETER
PI

Core concepts of quantum theory



PERIMETER INSTITUTE FOR THEORETICAL PHYSICS

Summary

- Purpose of enrichment presentations

- double-slit experiment

- Four of the most important features of quantum theory
  1. wave-particle duality
  2. superposition
  3. genuine randomness
  4. Heisenberg's uncertainty principle

- Why is quantum theory sometimes so tough to understand?

Summary

- Purpose of enrichment presentations
- double-slit experiment
- Four of the most important features of quantum theory
  1. wave-particle duality
  2. superposition
  3. genuine randomness
  4. Heisenberg's uncertainty principle
- Why is quantum theory sometimes so tough to understand?

Purpose of enrichment presentations

- For you, not (directly for) your students.

GOALS

1. Give you a deeper, richer understanding of the modern physics you teach.

2. Increase your confidence

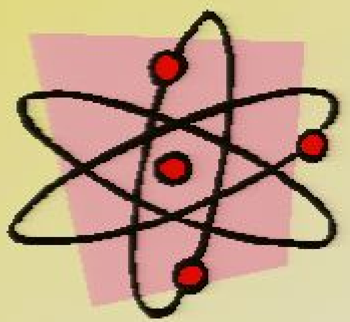
The core concepts philosophy

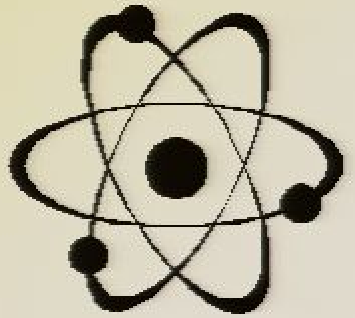
- What do you most want your students to walk out of your classroom on the last day remembering and understanding?
- What are the most important things about modern physics you would like to teach them?
- ONE ANSWER: The *core concepts* of quantum theory and special relativity.

"As teachers … we always seek to compress and simplify all the developments that have come before. We want to bring our students as quickly as possible to the frontier of current understanding. From this perspective, the actual history, which involves many variants and many missteps, is only a hindrance."
— David Politzer, 2004 Nobel prize winner in physics.

- ahistorical

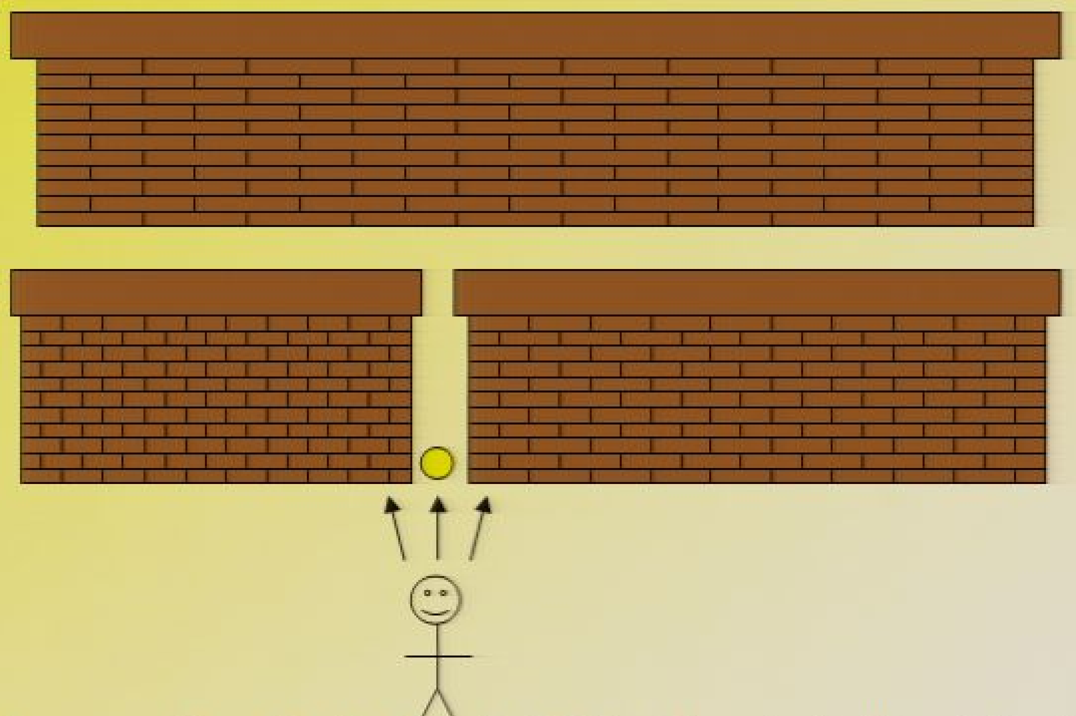
- given that you have a very limited time in which to teach modern physics, history can be a distraction





Double-slit experiment

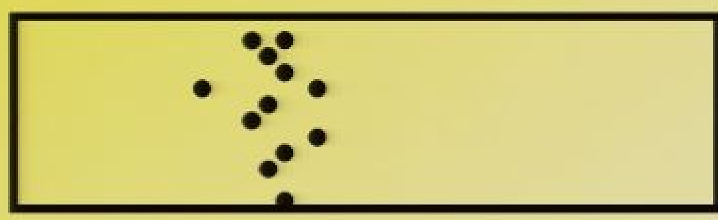
Imagine a brick wall with a narrow vertical slit. Behind it is a solid brick wall.

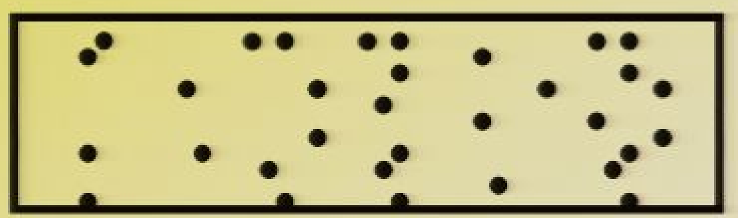


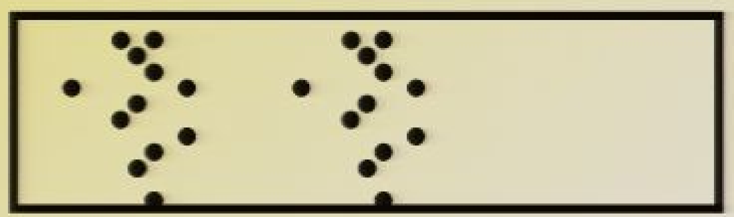
What would happen if we had a bucket full of tennis balls, picked them up one by one, dipped them in black paint, and then threw them *haphazardly* (i.e. the balls do *not* follow identical trajectories) at the first wall from in front of it?

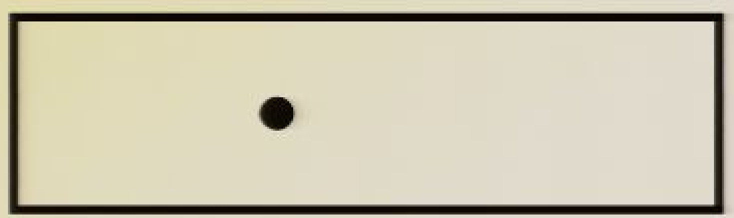
After we've thrown, say, 1000 tennis balls, what would the rear wall look like (roughly speaking)?

Discuss with those around you

a) 

b) 

c) 

d) 

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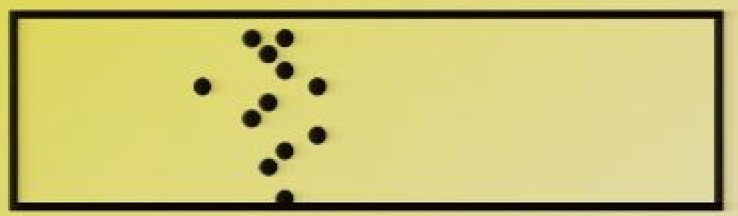

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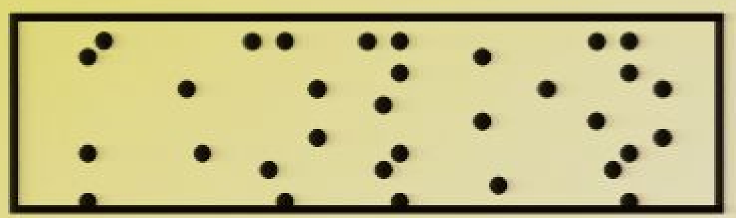

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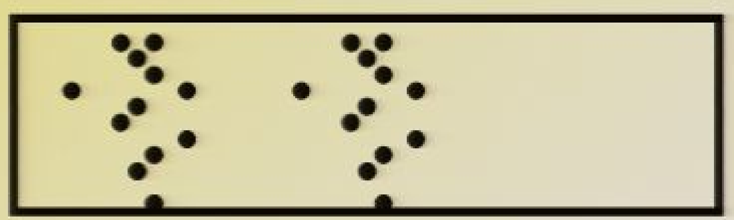

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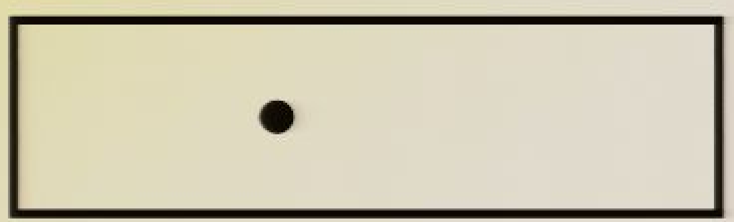

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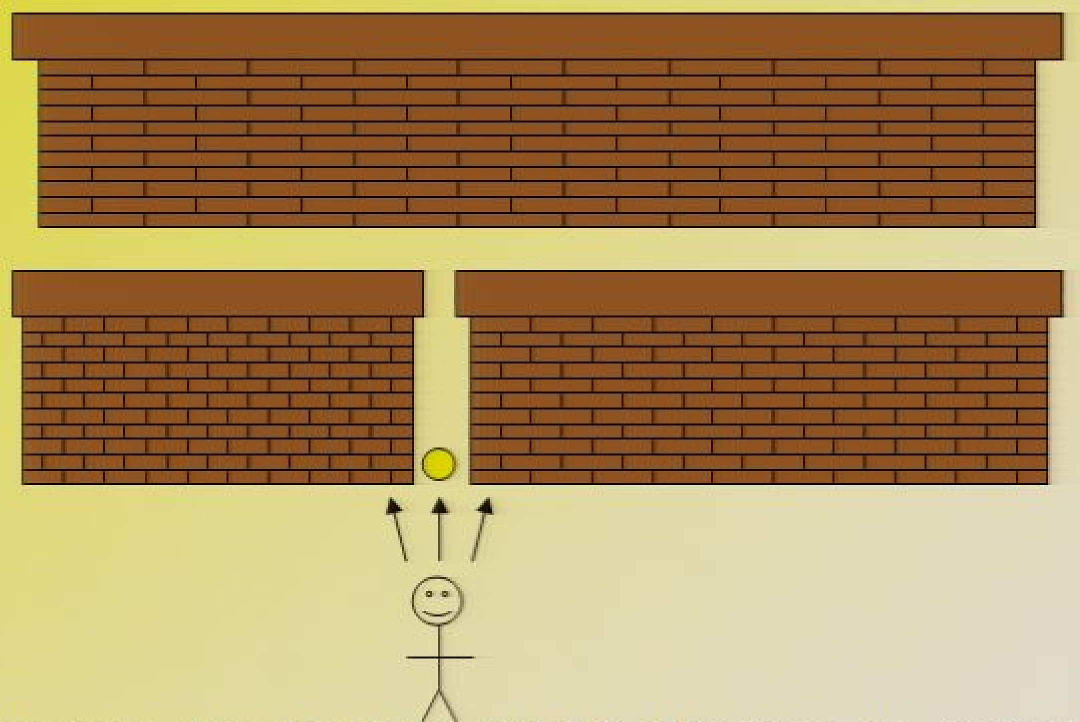

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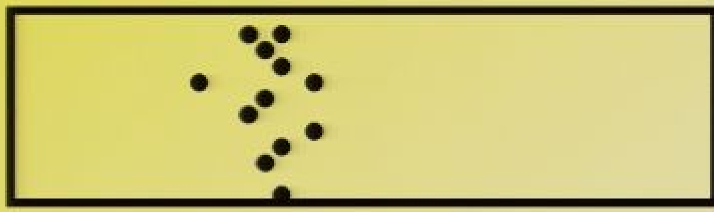

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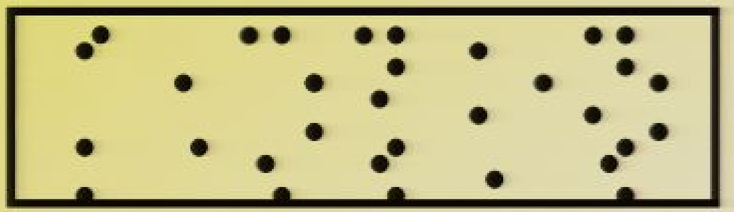

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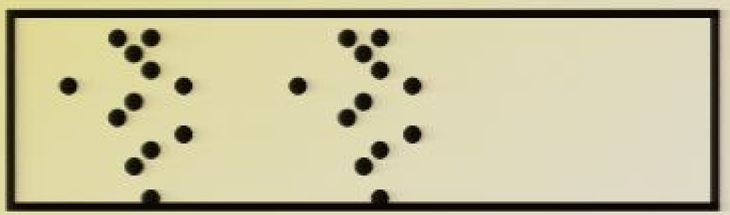

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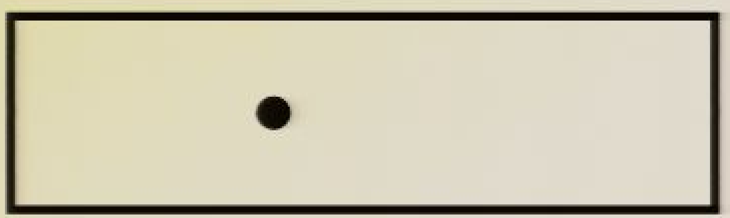
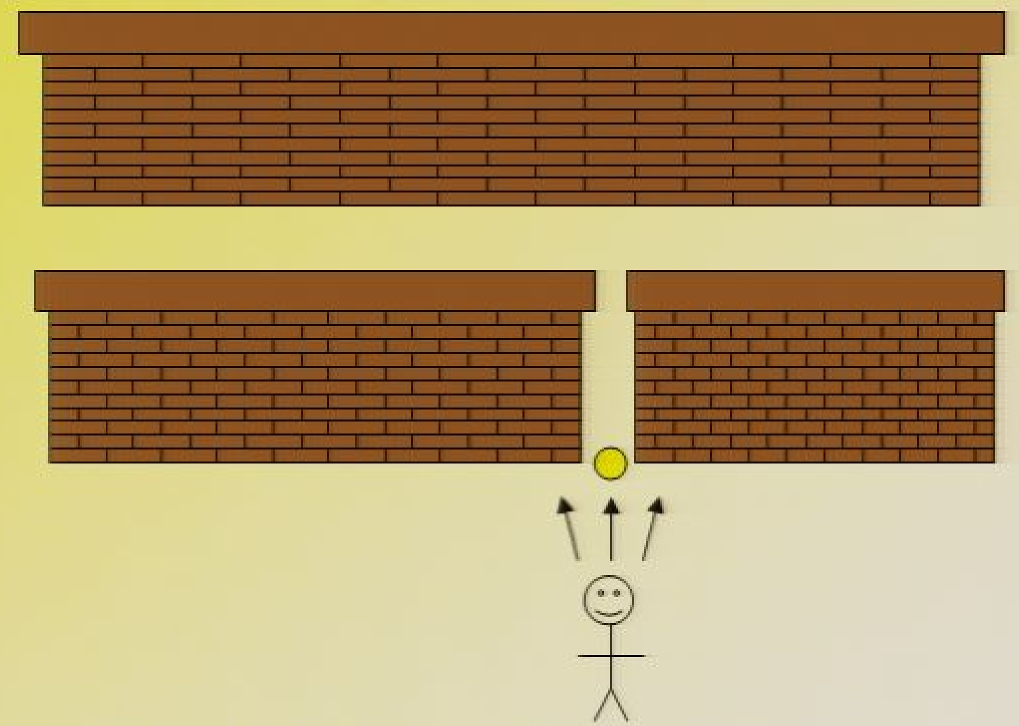
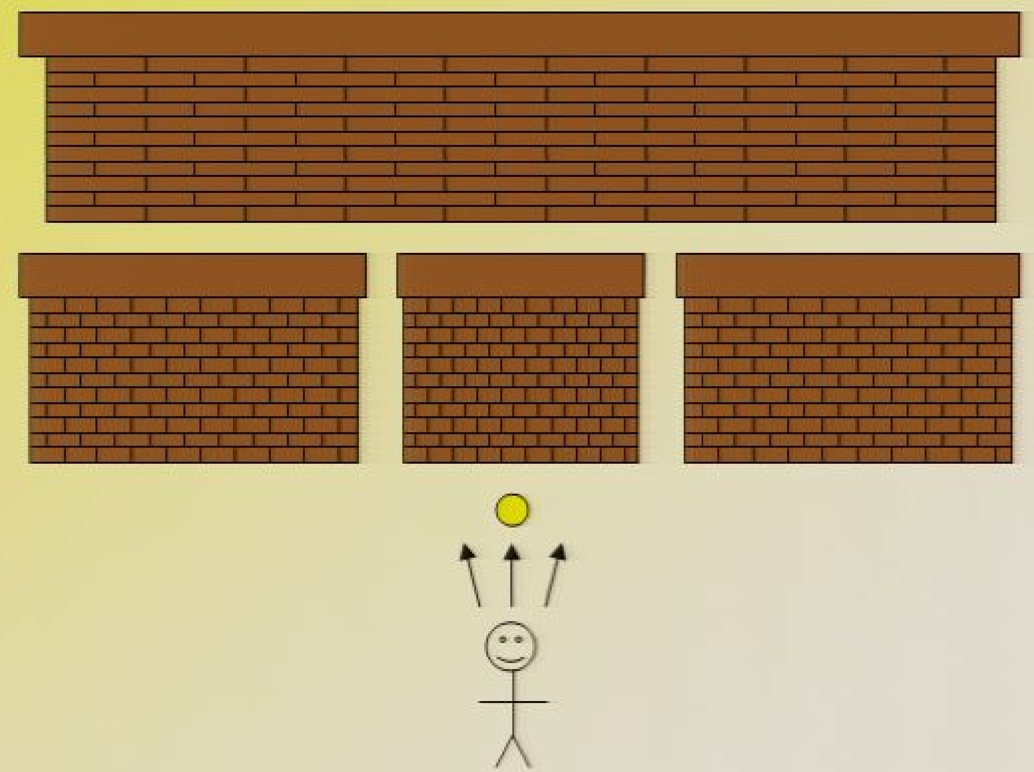


- Imagine that we move the slit in the first wall to another location, as shown below, and again throw 1000 paint-dipped tennis balls.

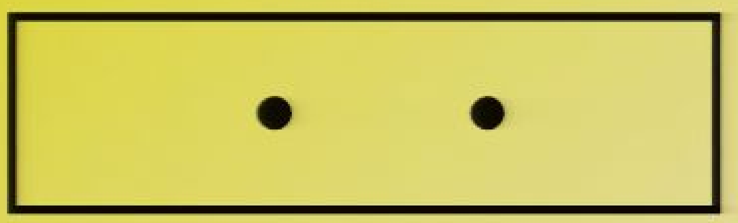


- Same pattern on the final wall, just shifted along.

- Next, open both slits in the first wall and throw 1000 tennis balls towards it haphazardly from in front of it.



- What sort of pattern do we see (roughly)?



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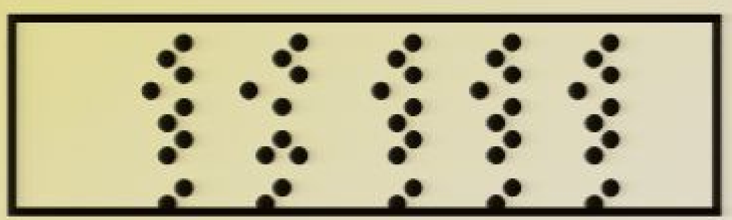

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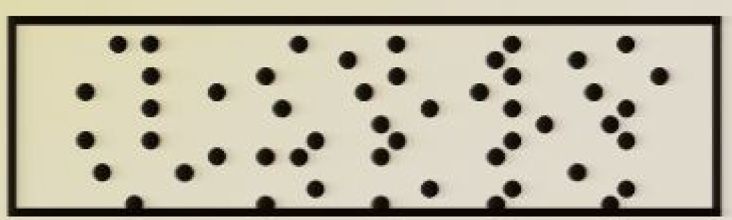
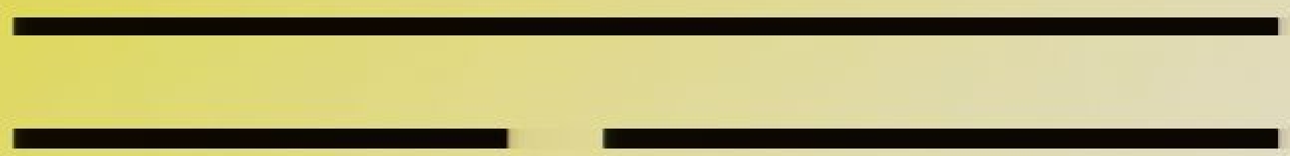


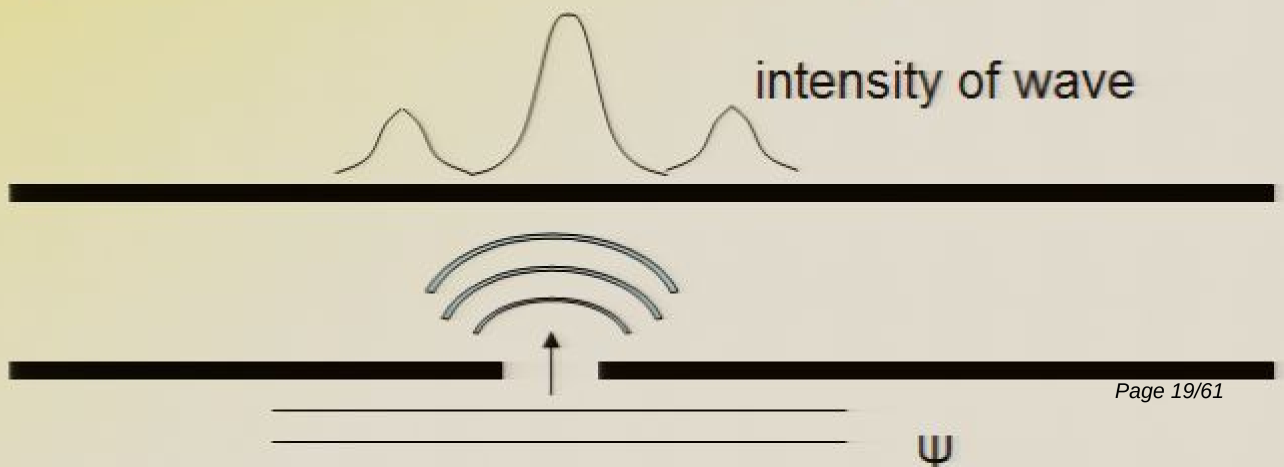
- Pattern seen illustrates typical *particle-like* behaviour. Could replace tennis balls by billiard balls, bullets, rocks etc.

Waves

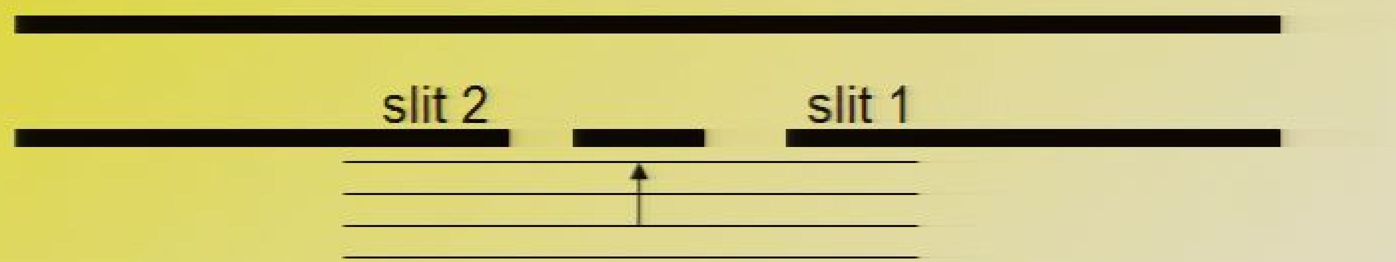
- Consider a similar sort of set up (in essence) but with water waves replacing the tennis balls.
- eg. a sea wall with a gap



- Imagine a plane wave incident at right angles hits the wall. What happens?
- wave represented by specifying the amplitude everywhere (scalar field ψ)
- Diffraction
(N.B. Details of pattern depend on wavelength, slit width & distance between the two walls)

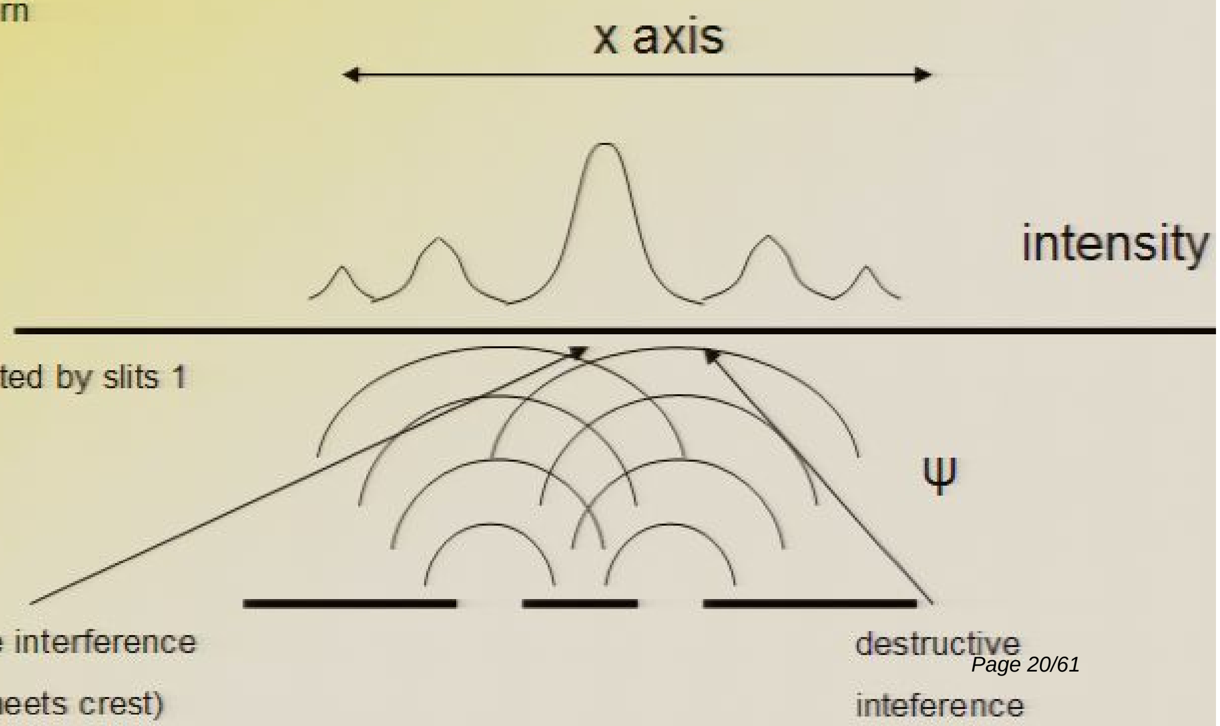


- Consider a wave incident on a sea wall with two slits.



- Get standard double-slit interference pattern

$$\psi(x) = \underbrace{\psi_{slit\ 1}(x) + \psi_{slit\ 2}(x)}_{\text{superposition}}$$



- $\psi_{slit\ 1}(x)$ and $\psi_{slit\ 2}(x)$ are the waves generated by slits 1 and 2
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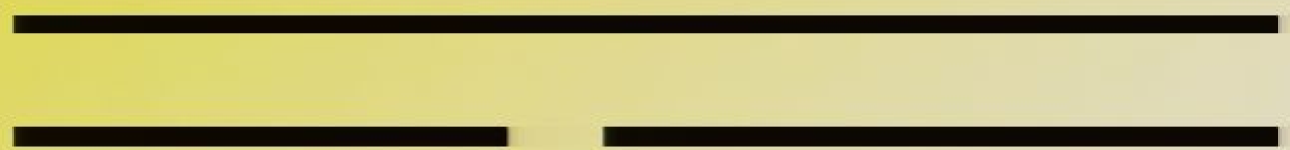

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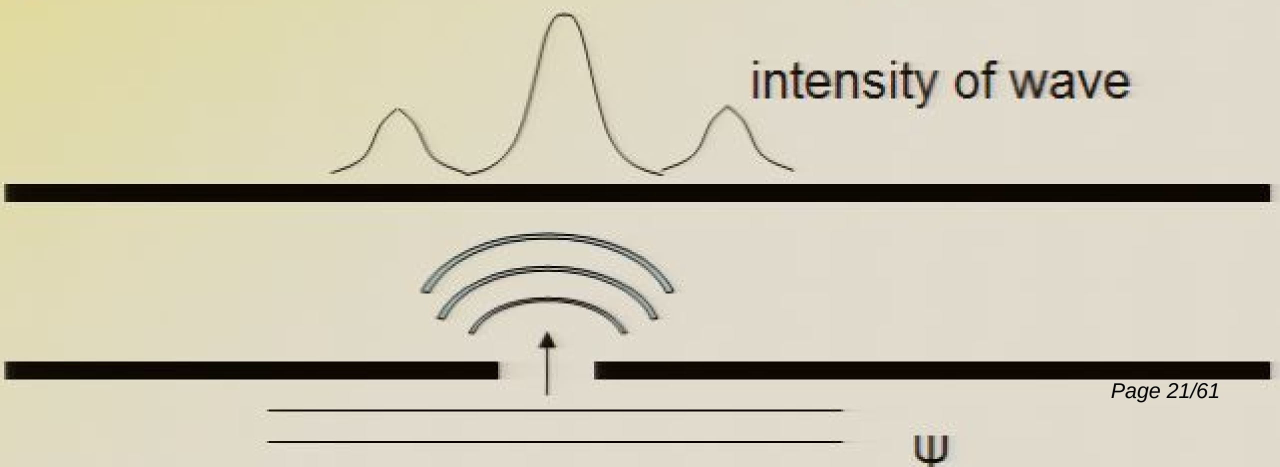
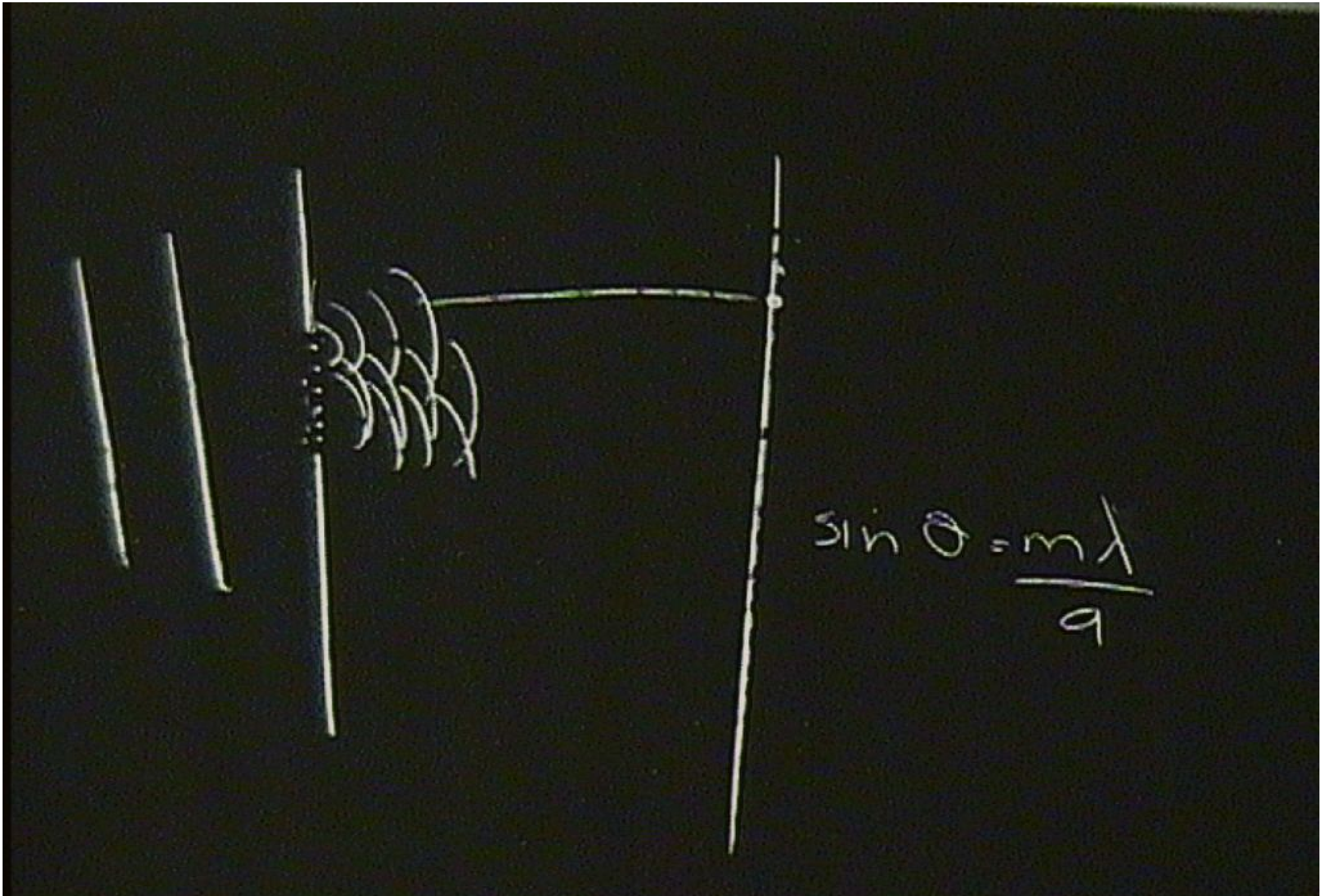
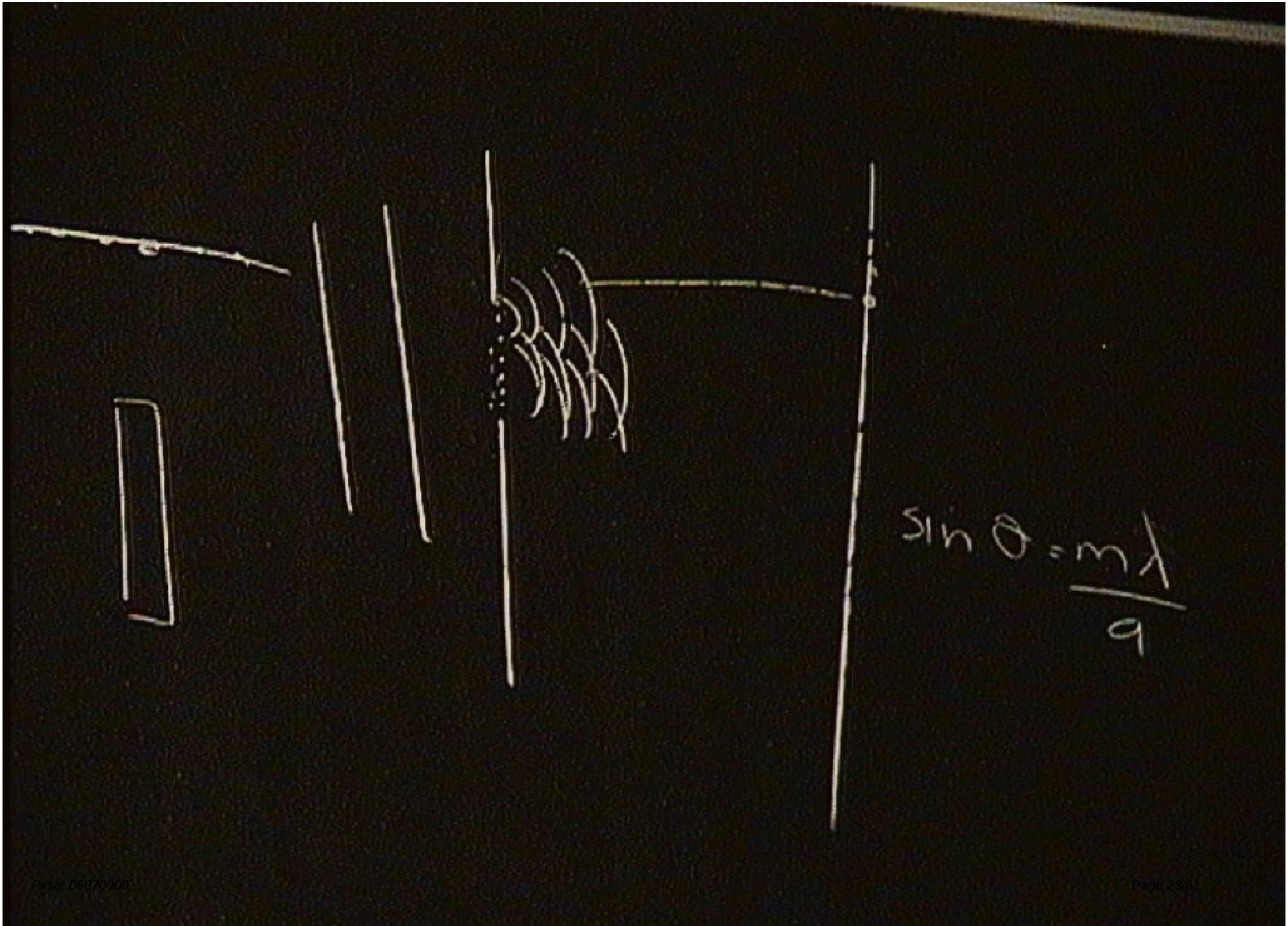



sin θ = mλ / a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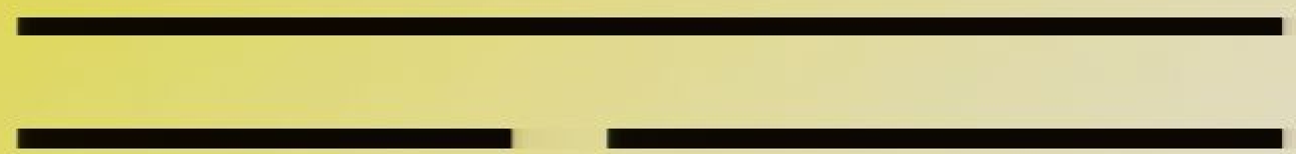

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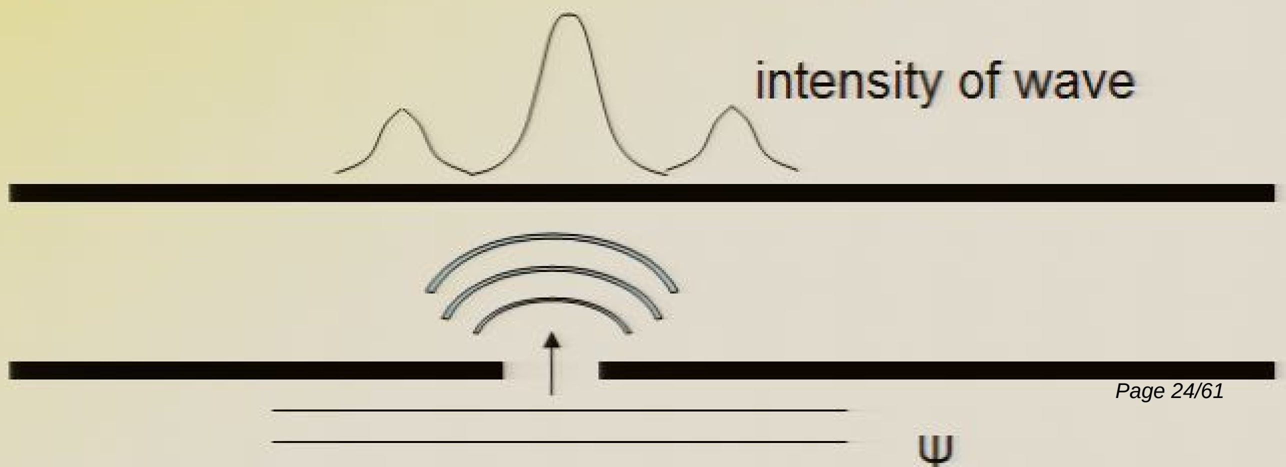

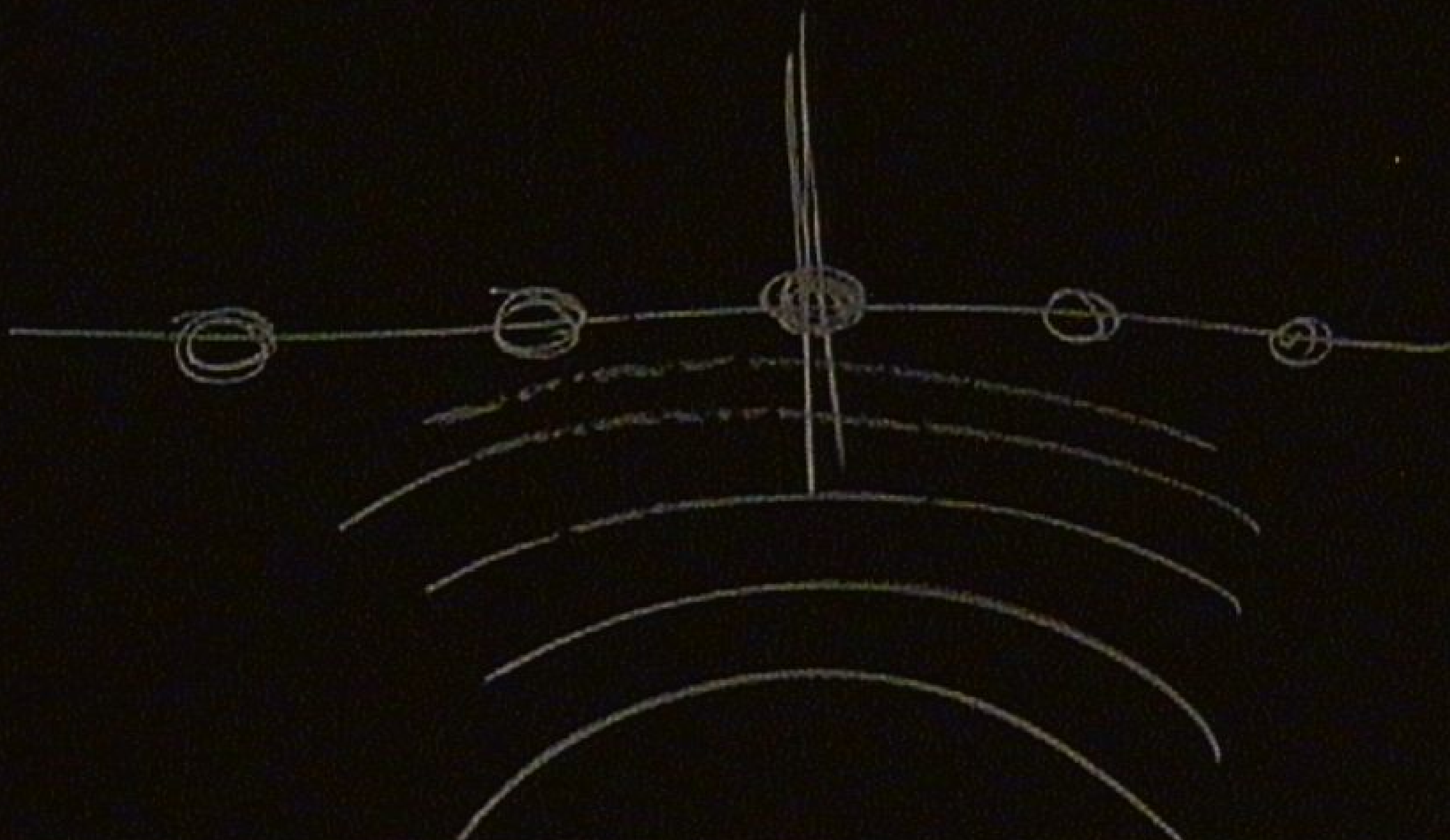

What happens with electrons?

- Same essential set up. Replace tennis balls by electrons.
- Experiment actually been done.
  (Reference: A. Tonomura, et al., *Demonstration of single-electron buildup of an interference pattern*, Am. J. Phys 57 (2), pp. 117-120 and http://www.hqrd.hitachi.co.jp/em/doubleslit.cfm)
- Let's consider what would happen with just slit 1 open.
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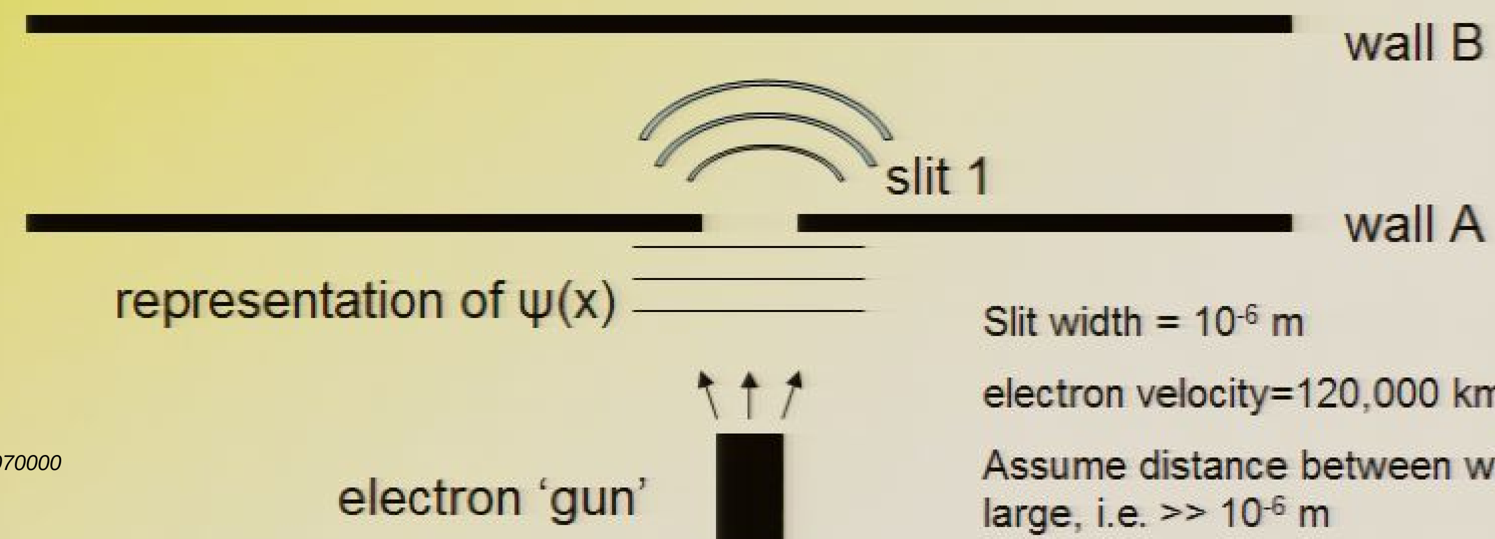

Slit width = 10^{-6} m

electron velocity=120,000 kms^{-1}

Assume distance between walls A and B is large, i.e. >> 10^{-6} m

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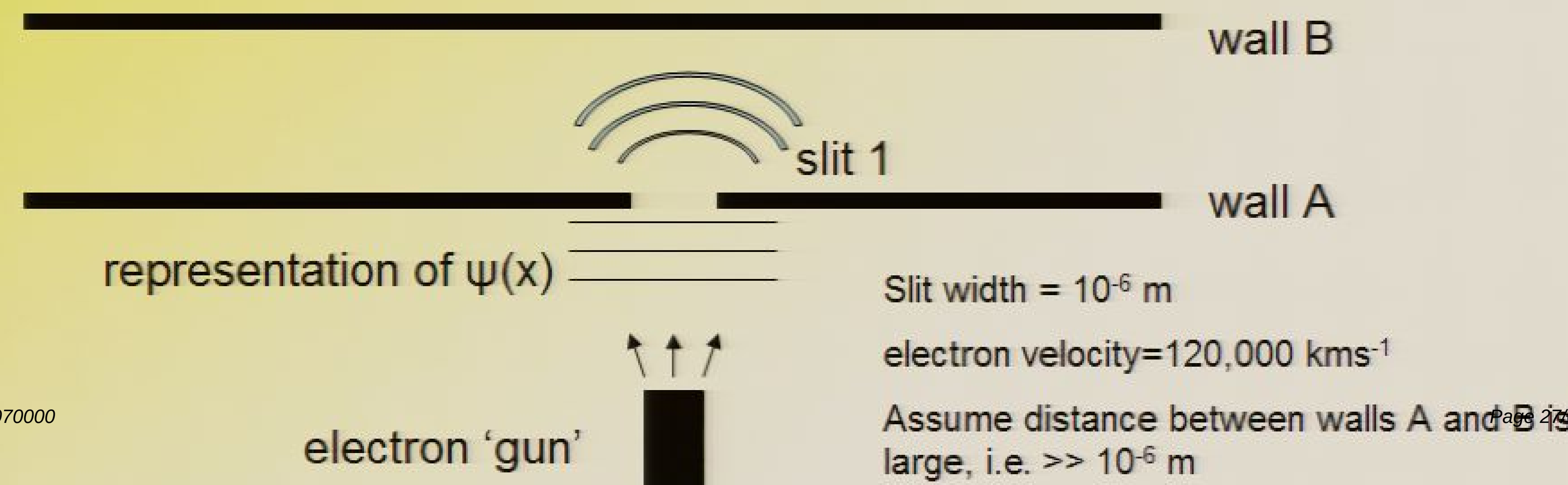

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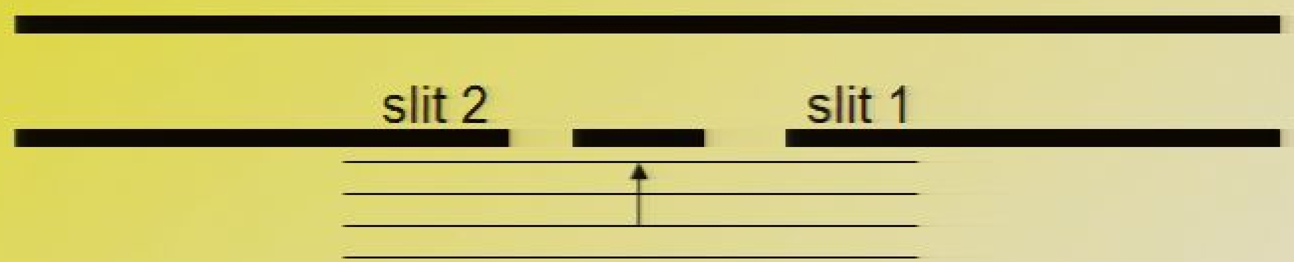

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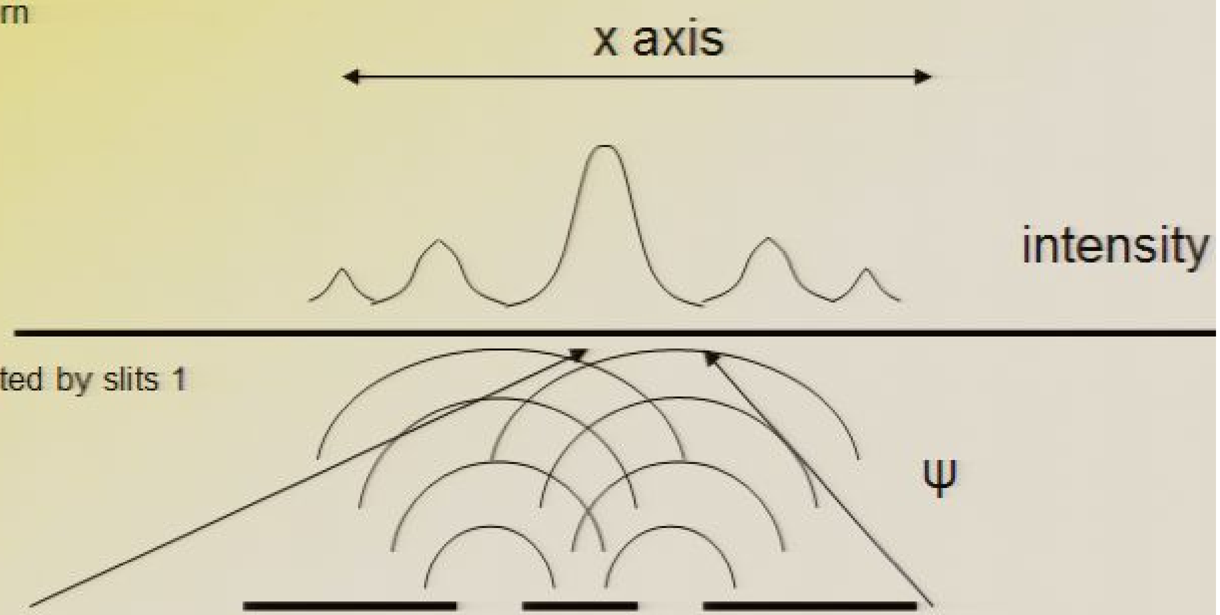

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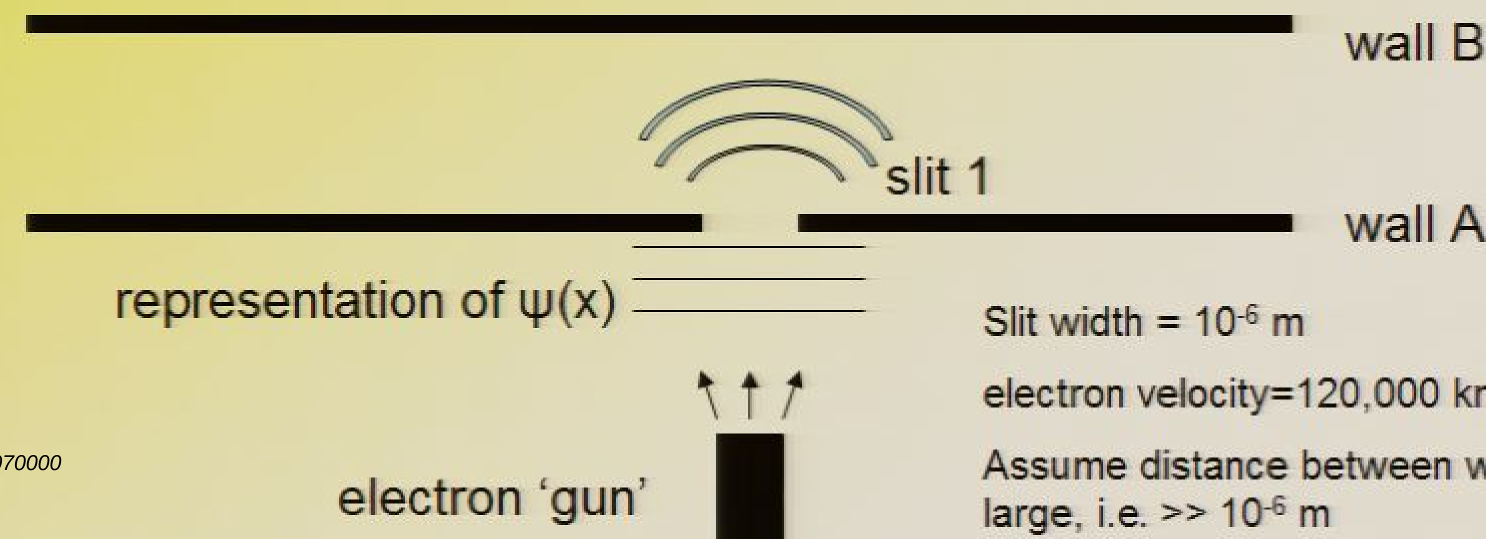

Slit width = 10^{-6} m

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Assume distance between walls A and B is large, i.e. >> 10^{-6} m

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

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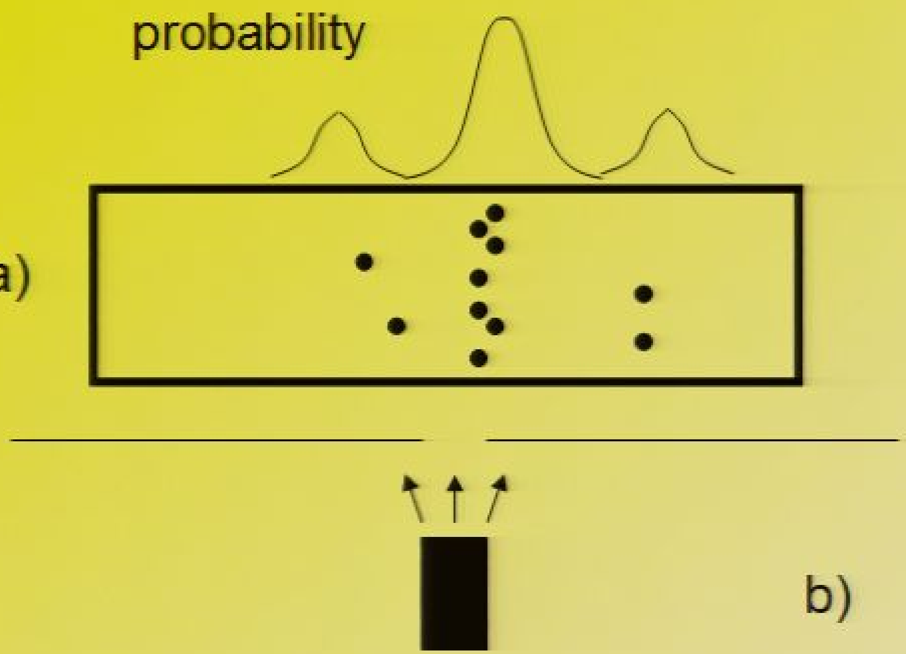

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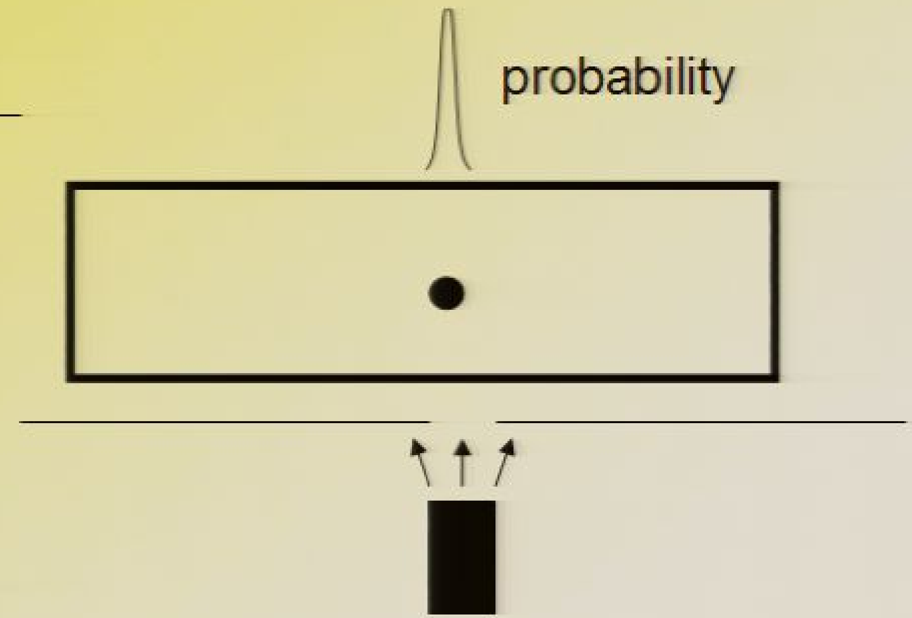

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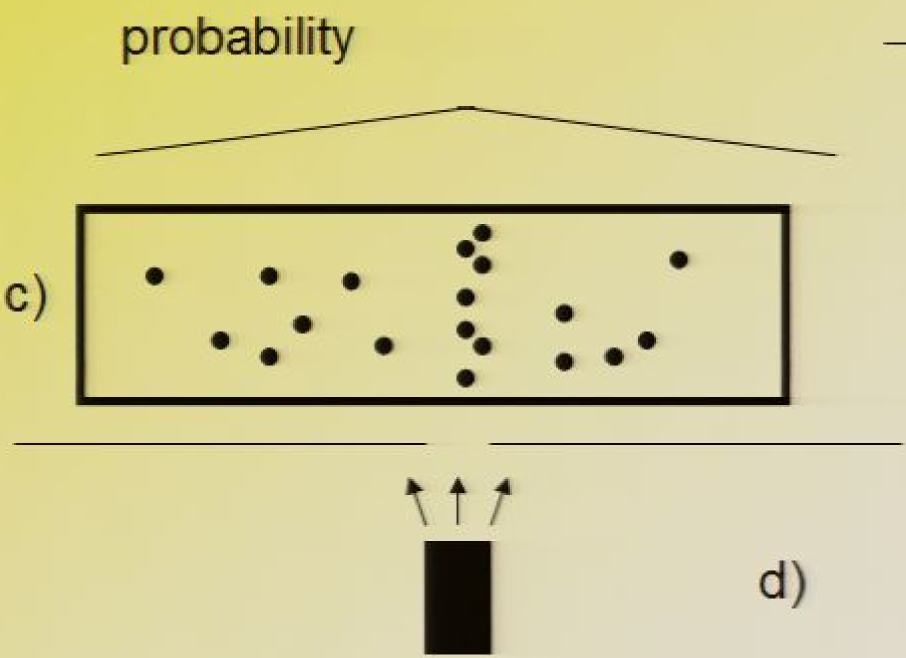

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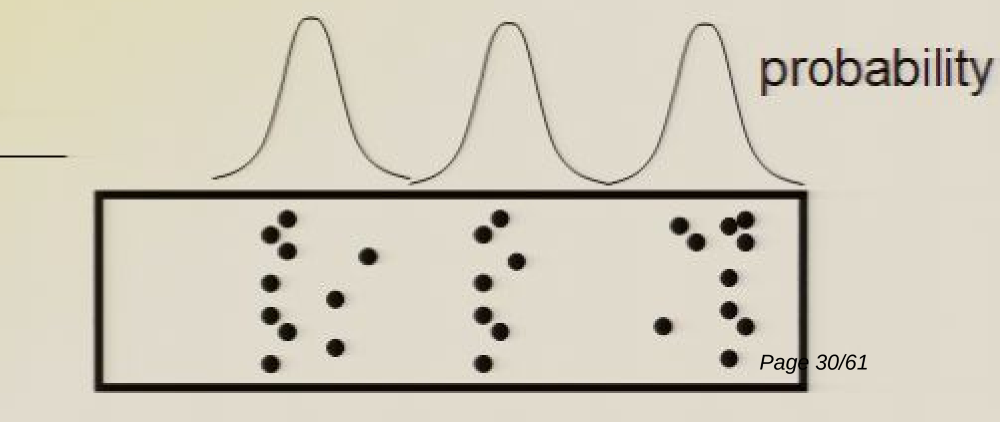

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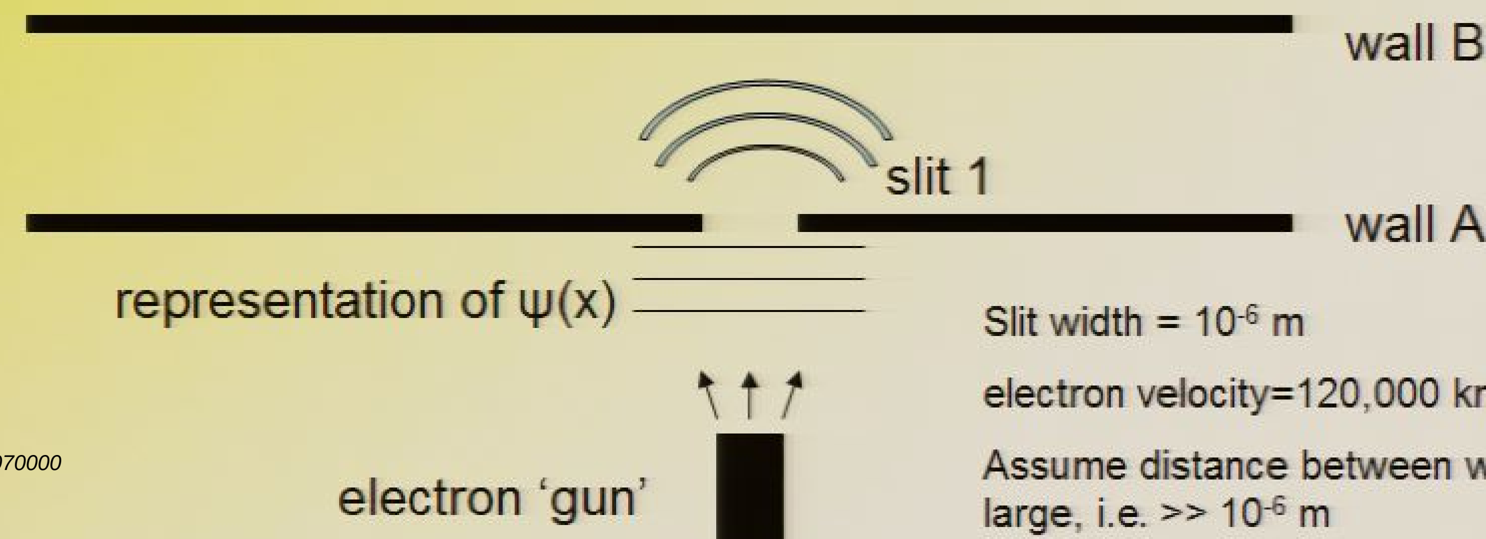

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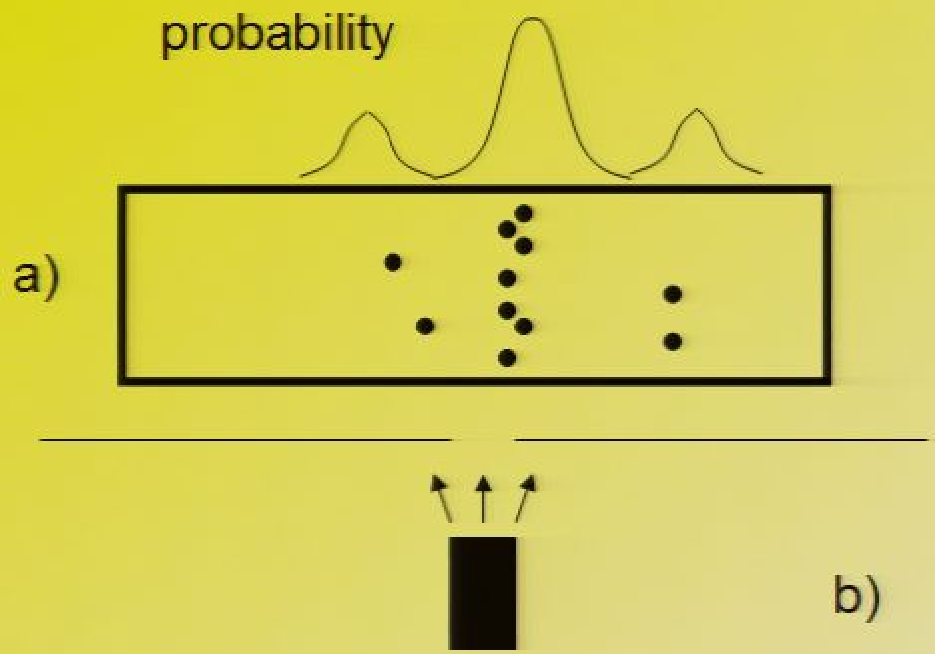

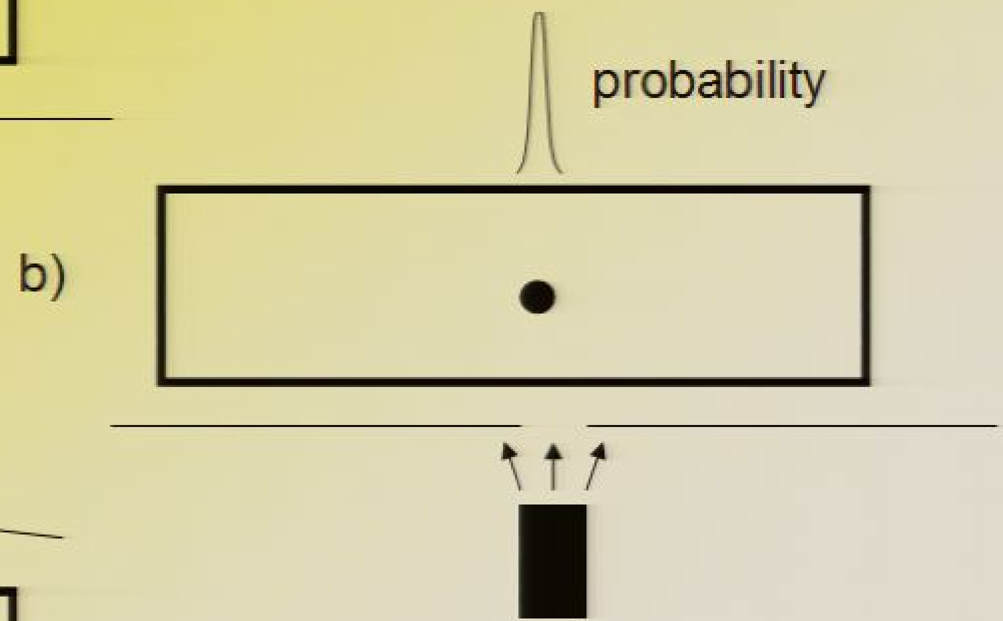

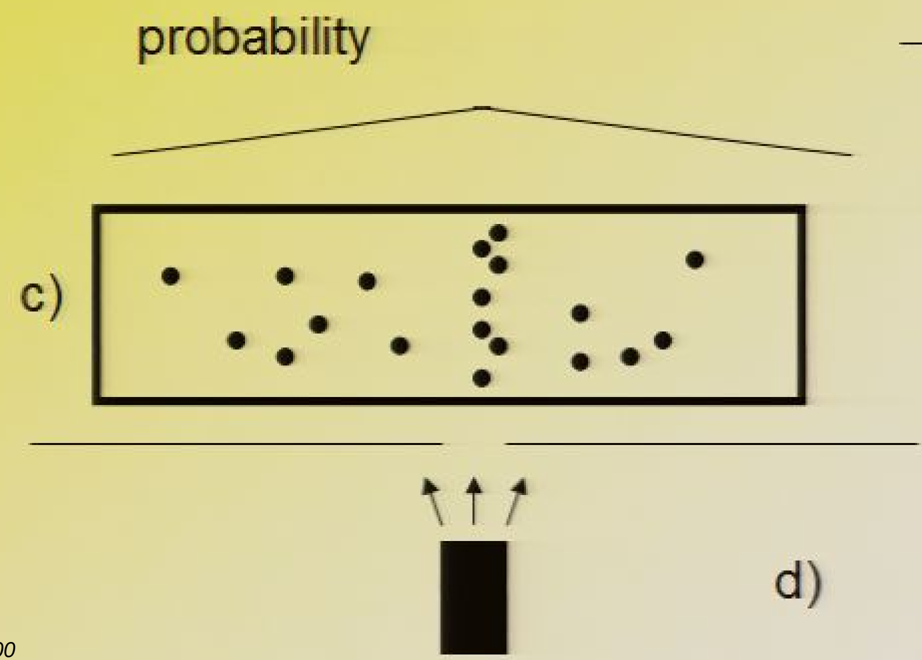

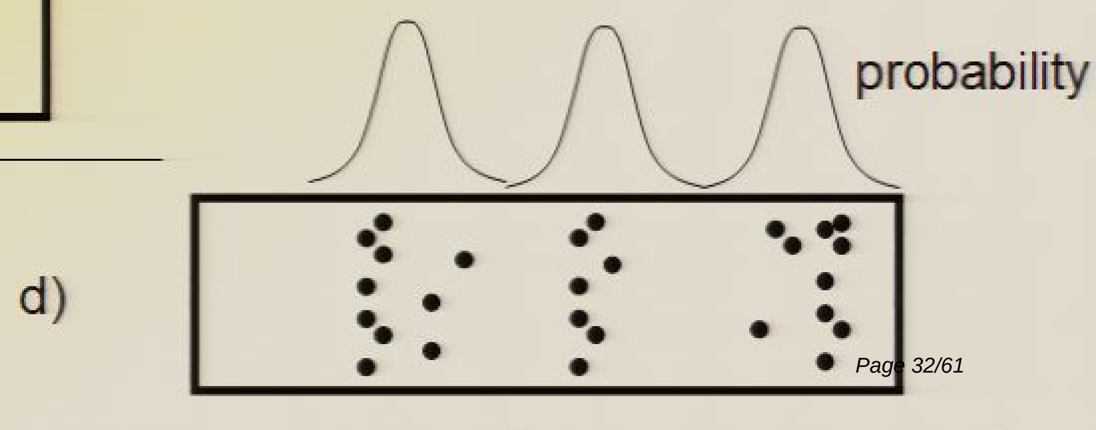

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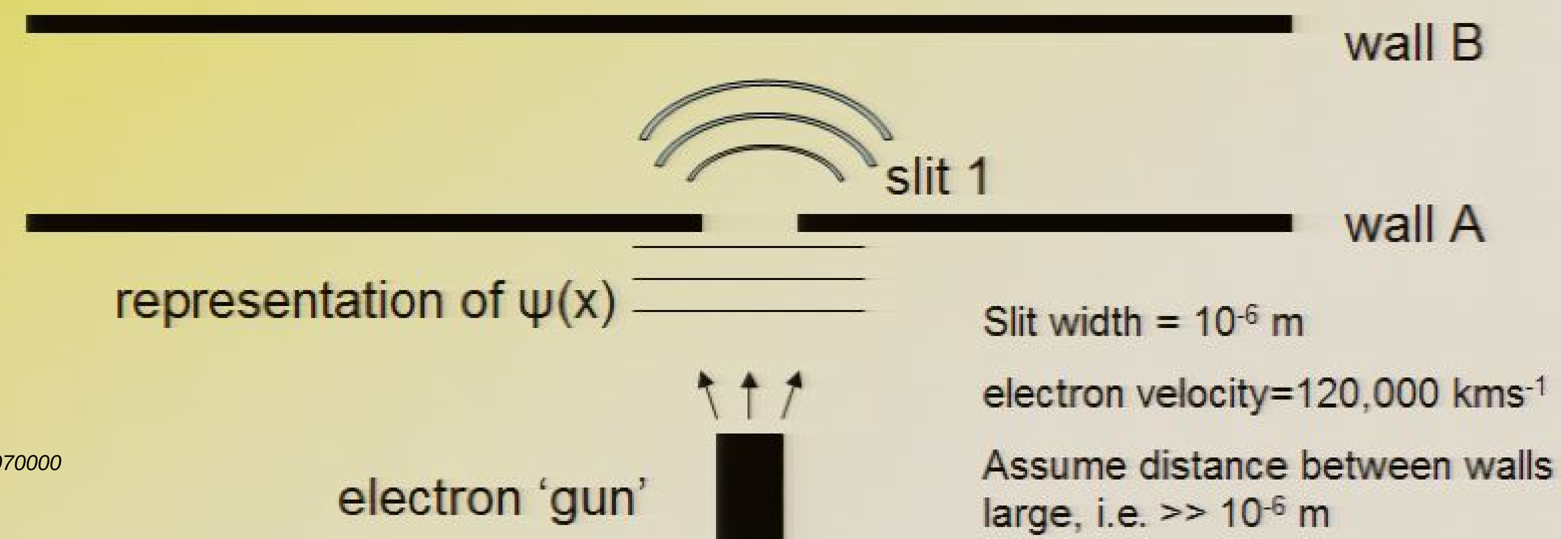

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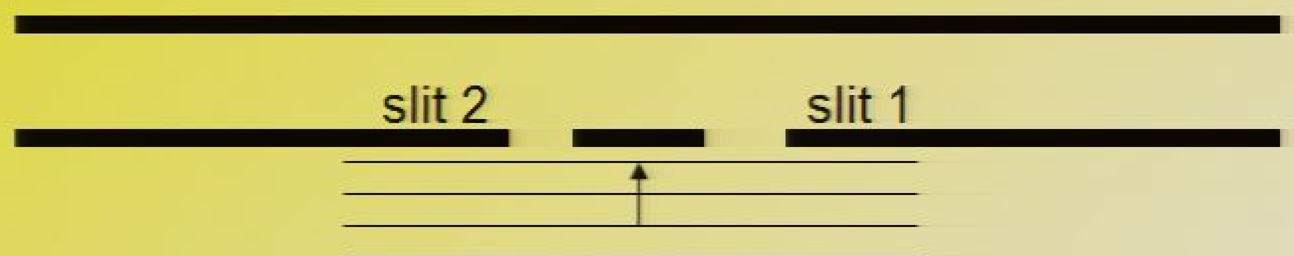

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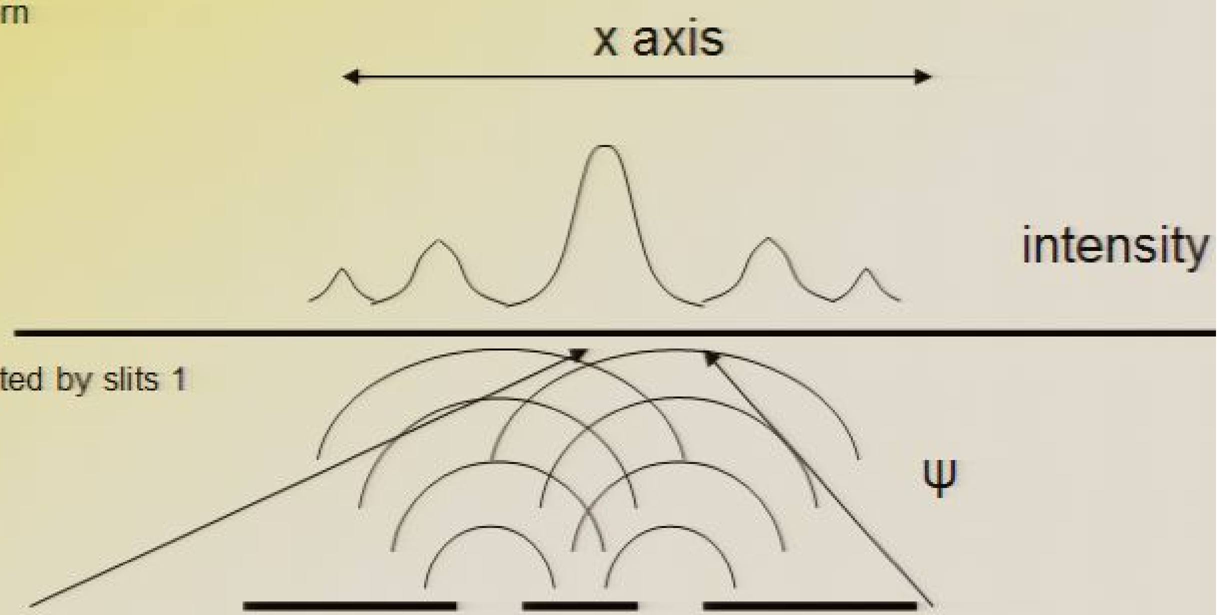

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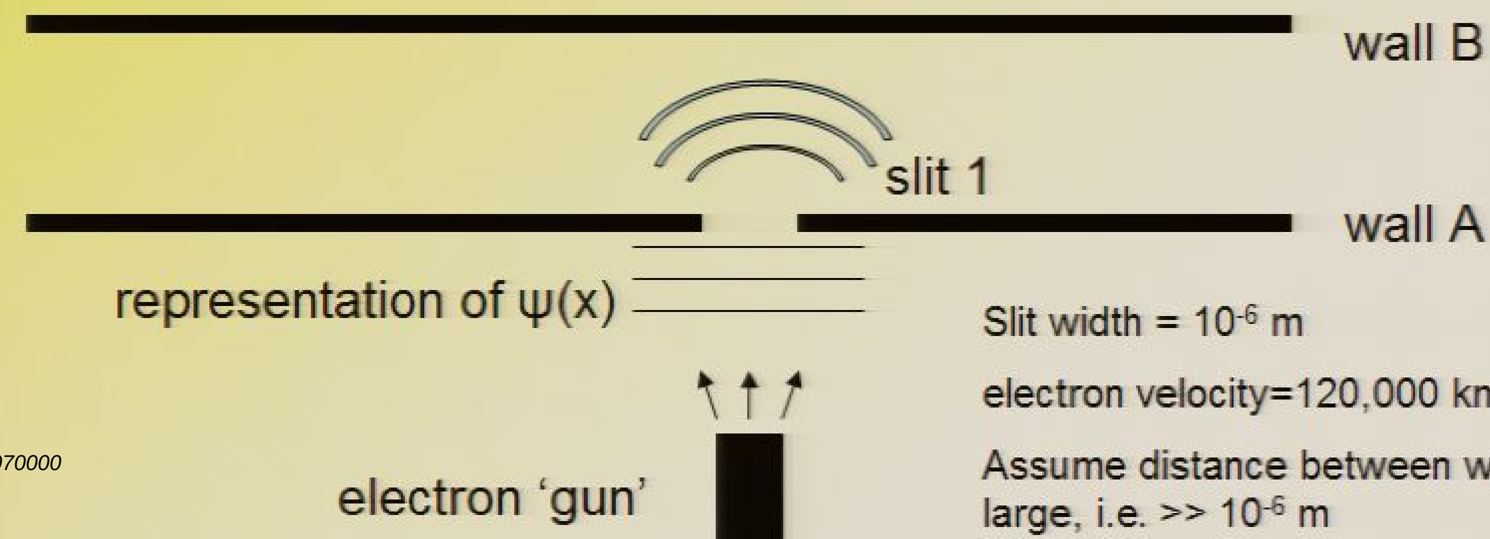
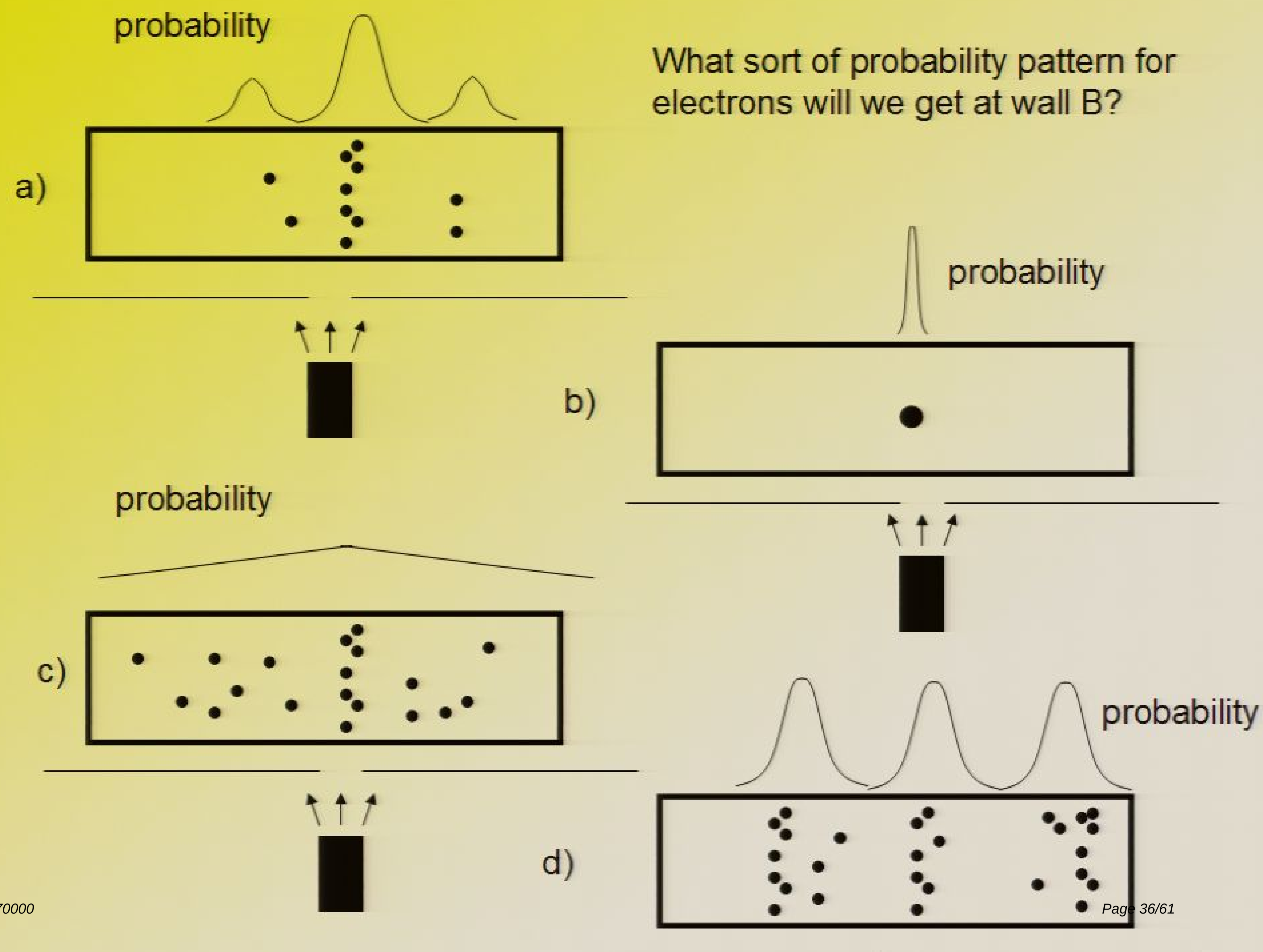


Slit width = 10^{-6} m

electron velocity=120,000 kms^{-1}

Assume distance between walls A and B is large, i.e. >> 10^{-6} m

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



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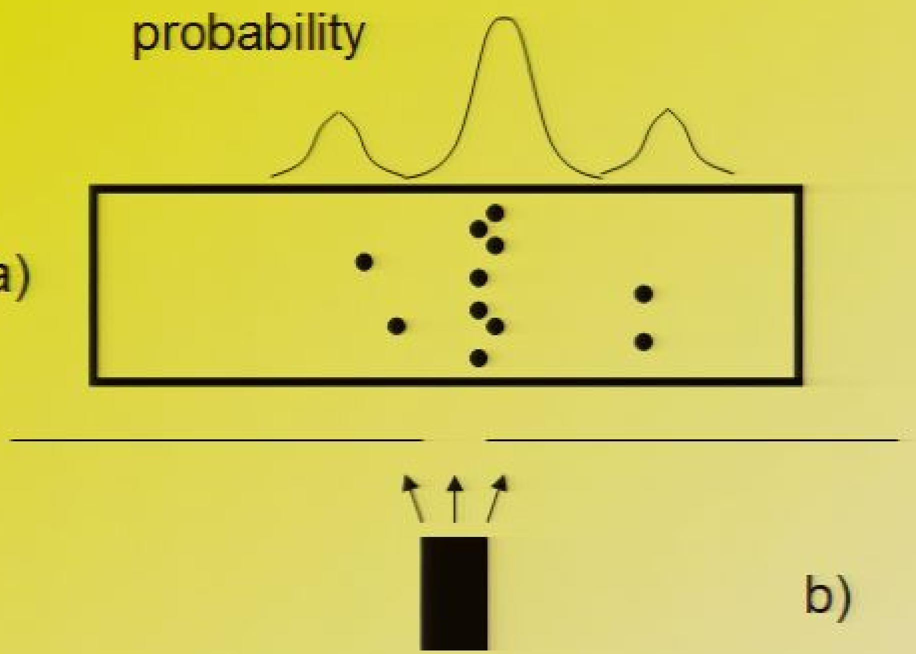
Two key points

- Electrons always hit wall B as localized particles.

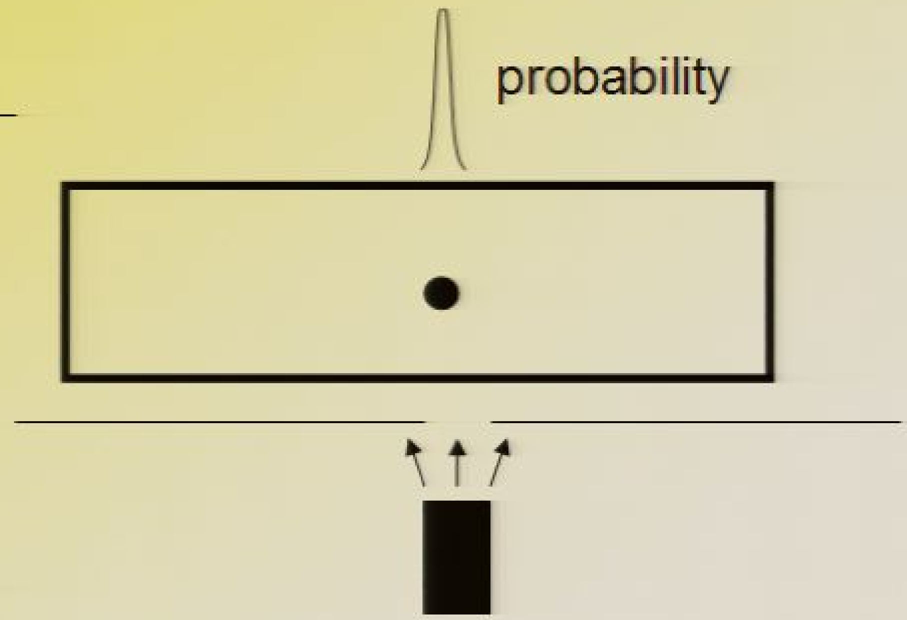
- Diffraction between walls A and B

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

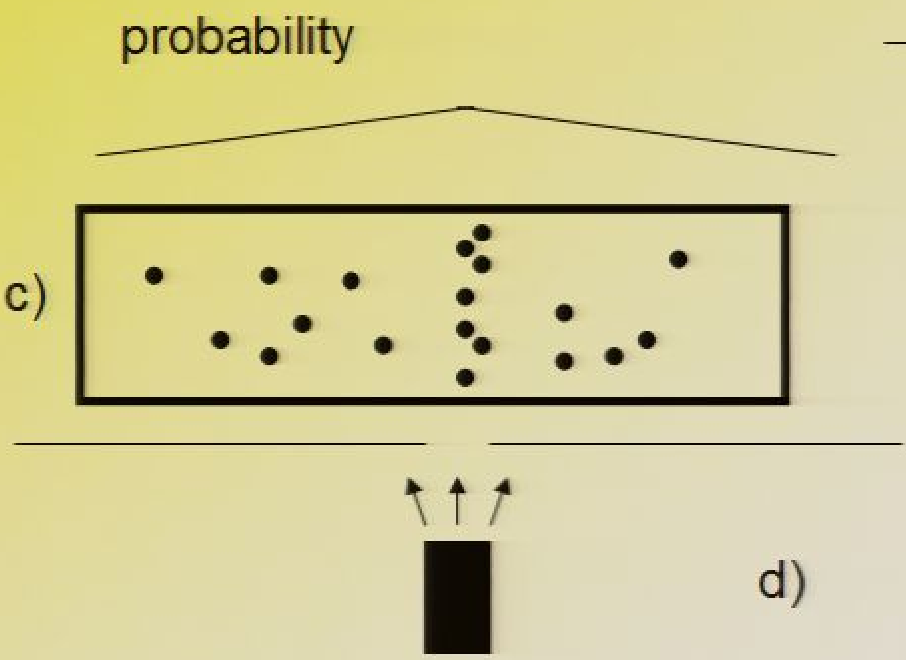
a)



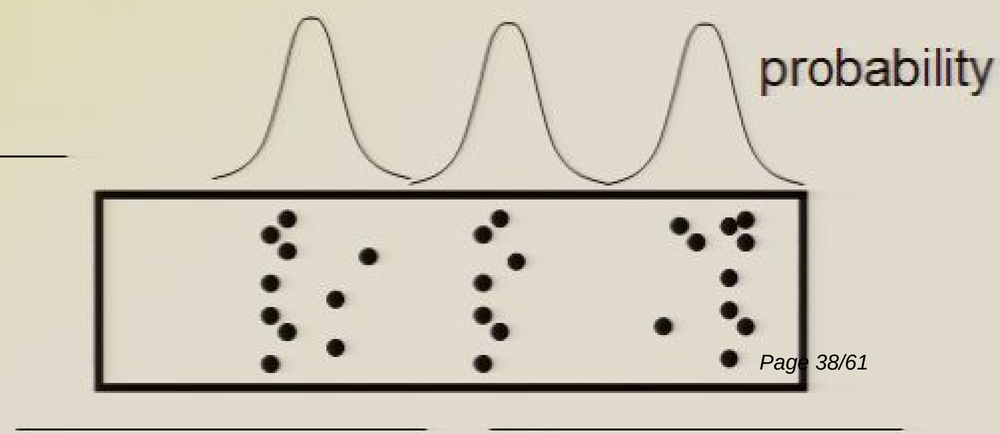
b)



c)



d)



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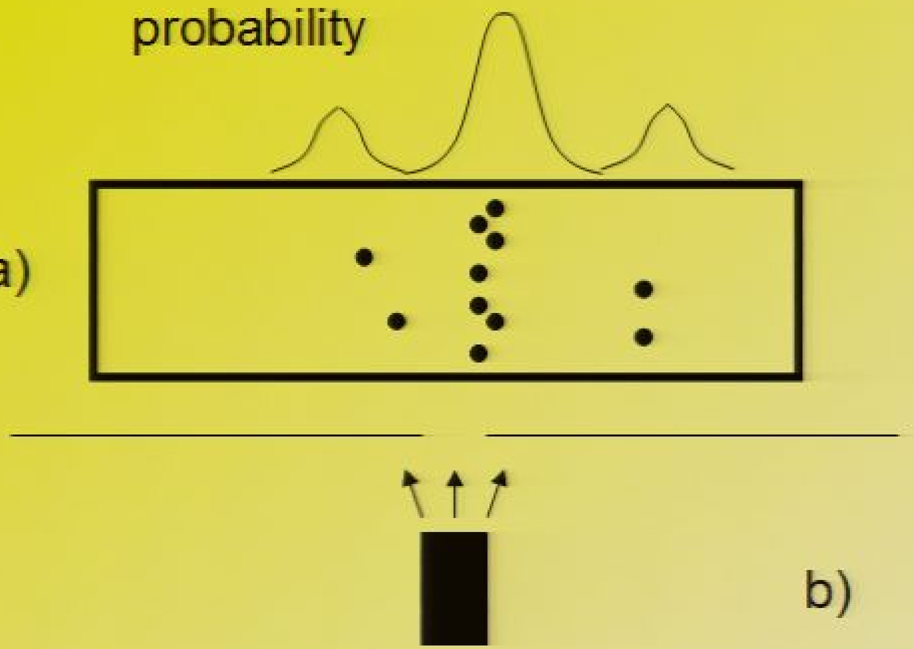

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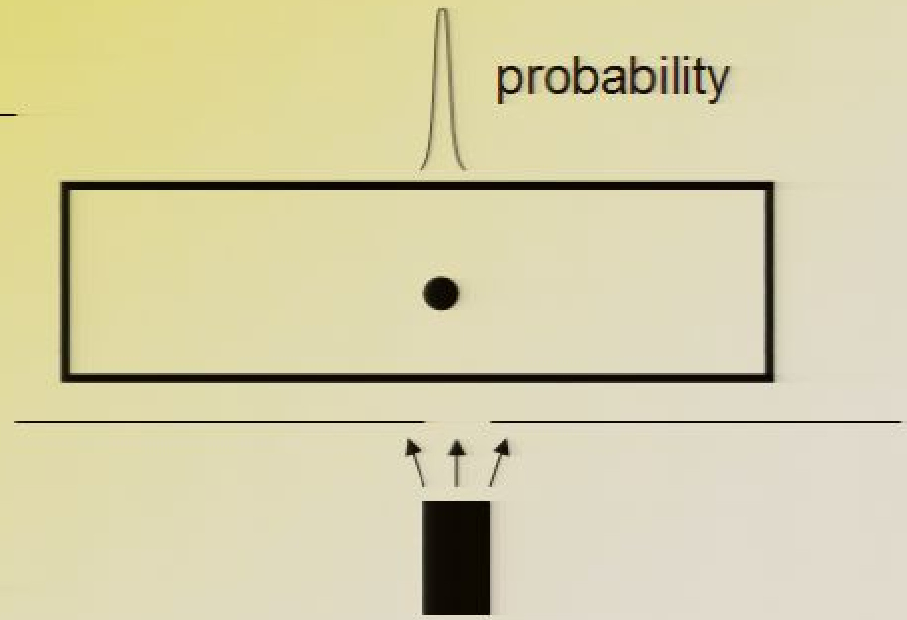

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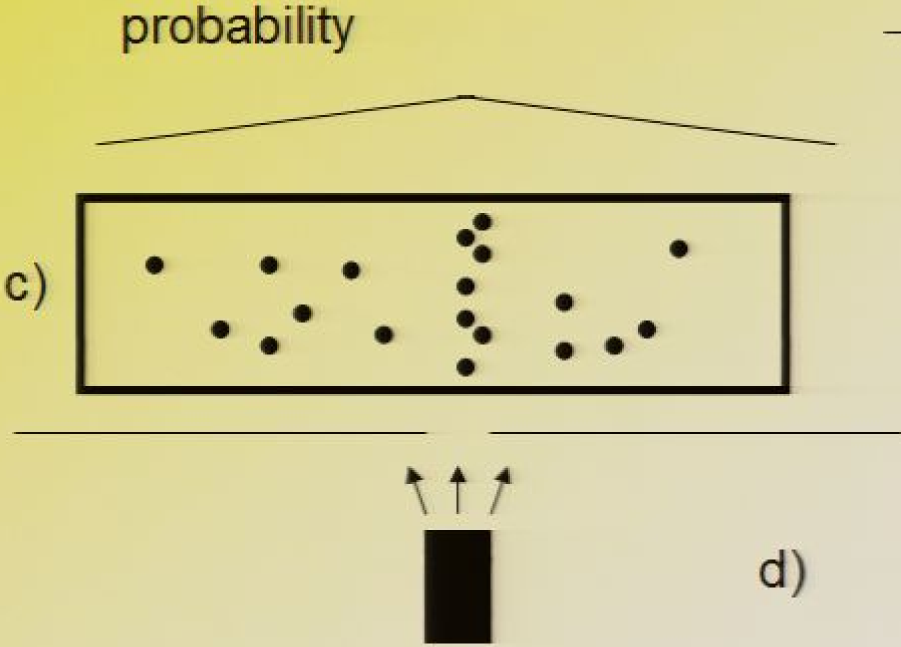
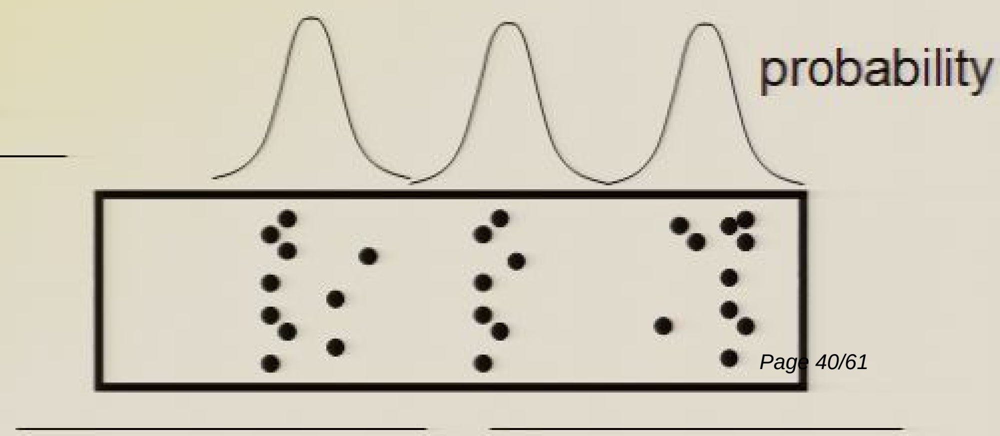


d)



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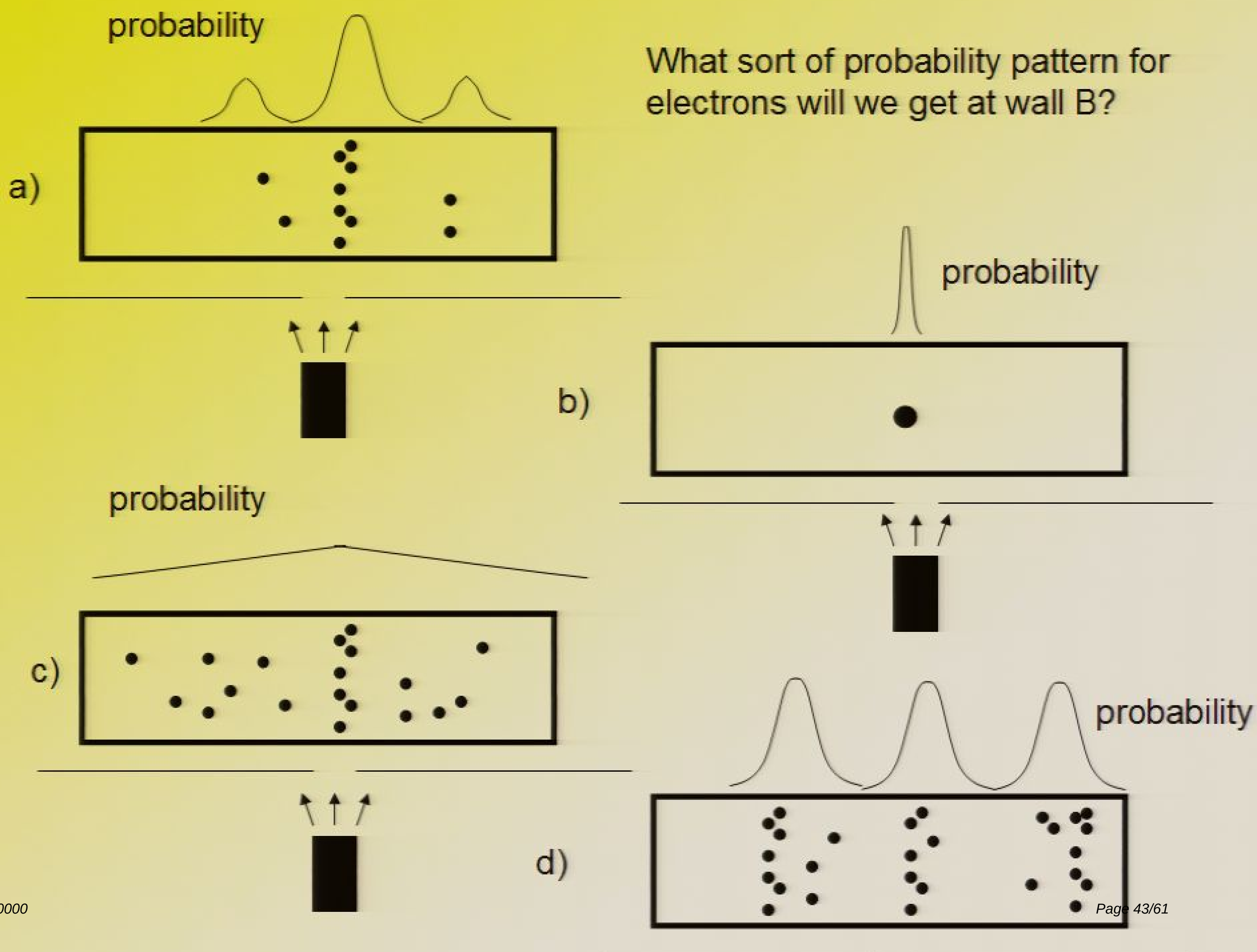

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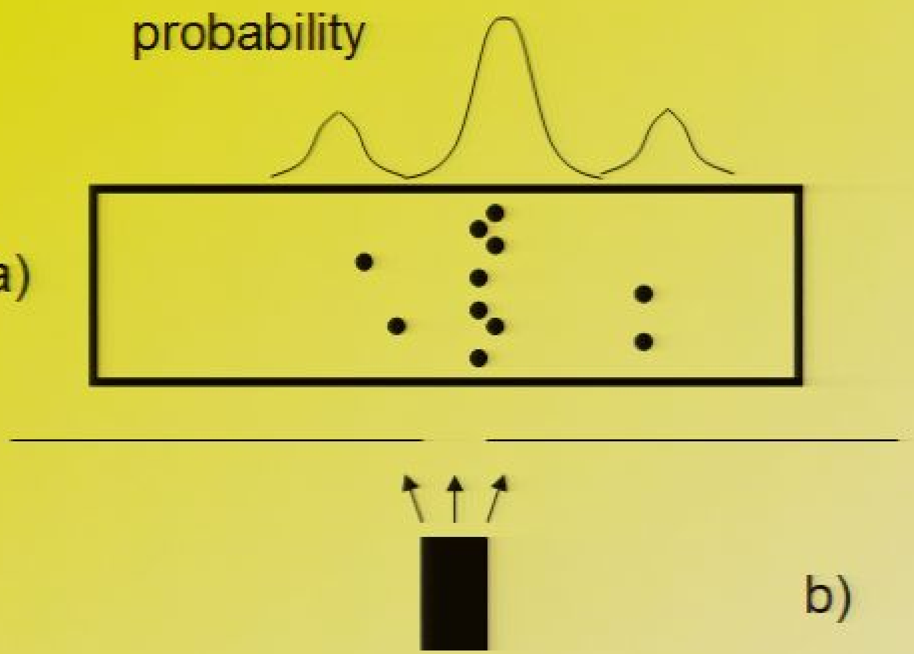

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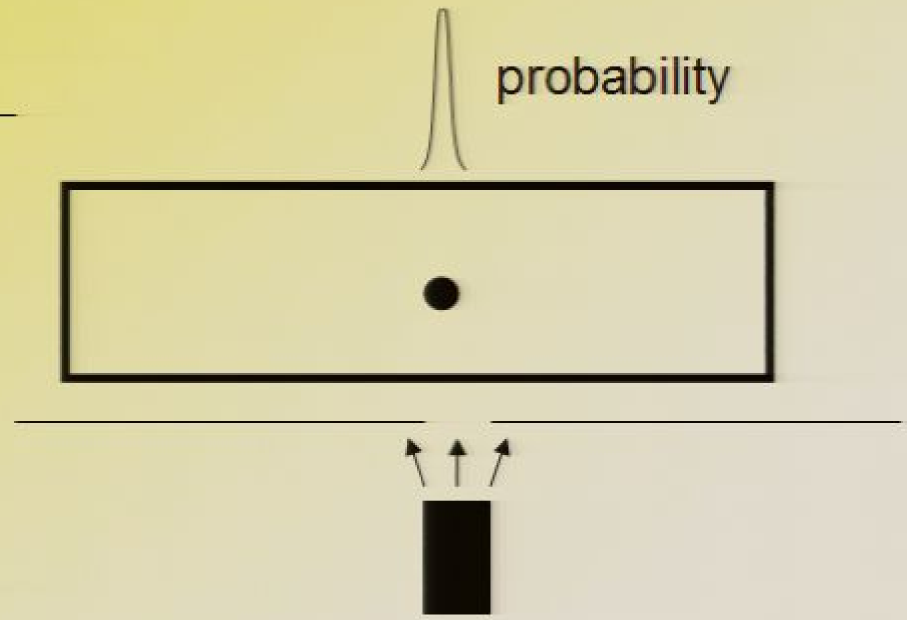

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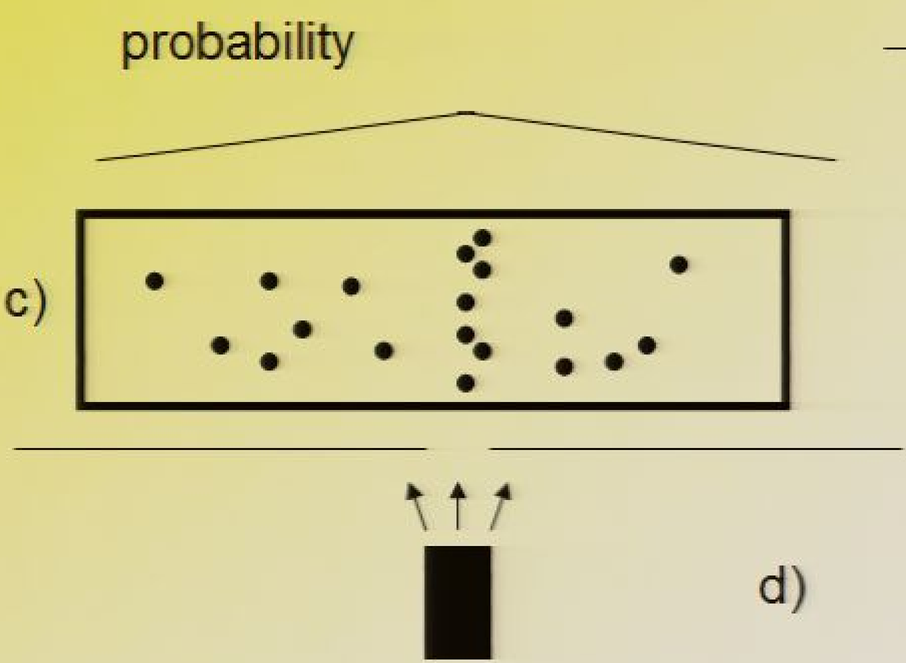

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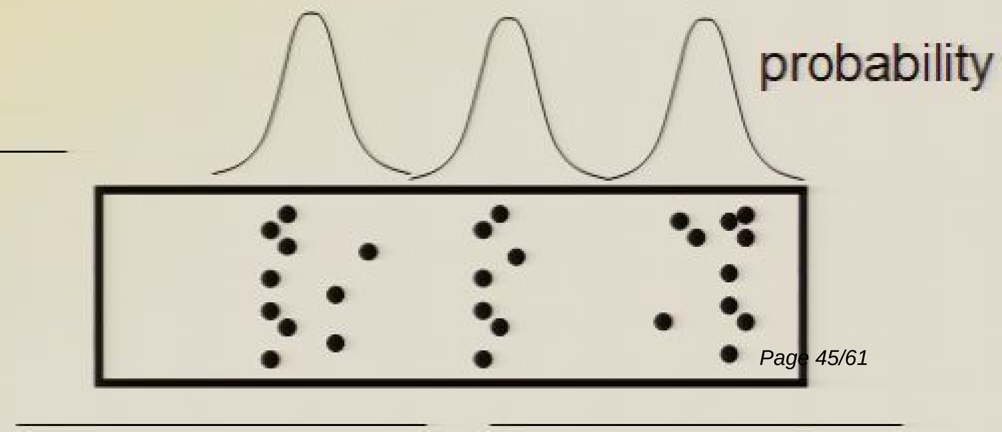
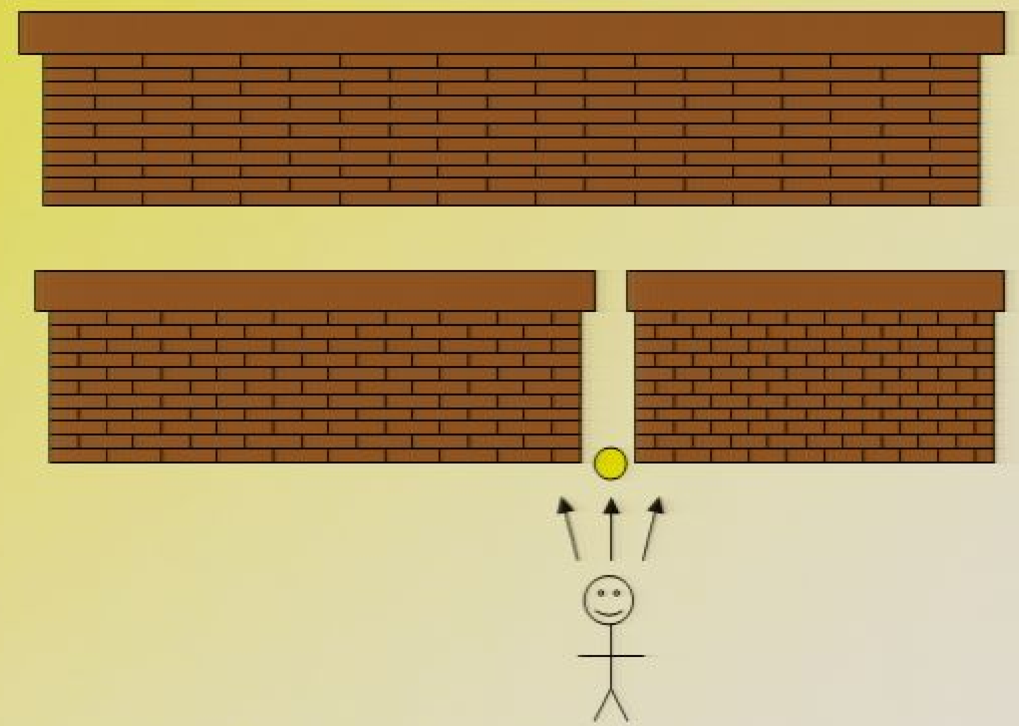
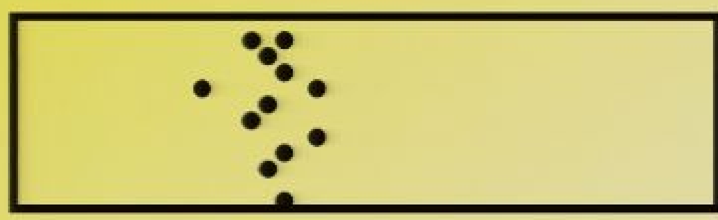


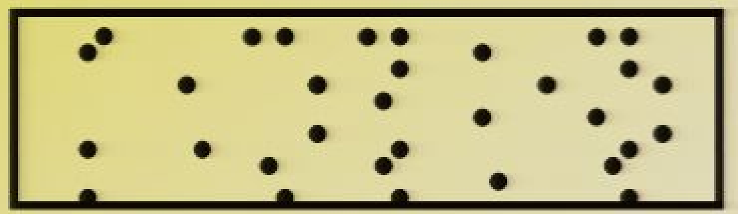
- Imagine that we move the slit in the first wall to another location, as shown below, and again throw 1000 paint-dipped tennis balls.

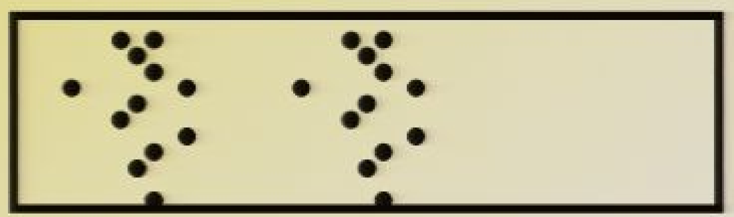


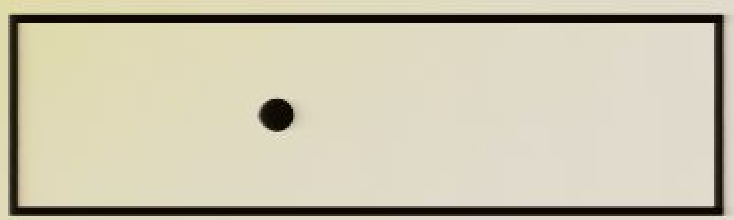
- Same pattern on the final wall, just shifted along.

Discuss with those around you

a) 

b) 

c) 

d) 

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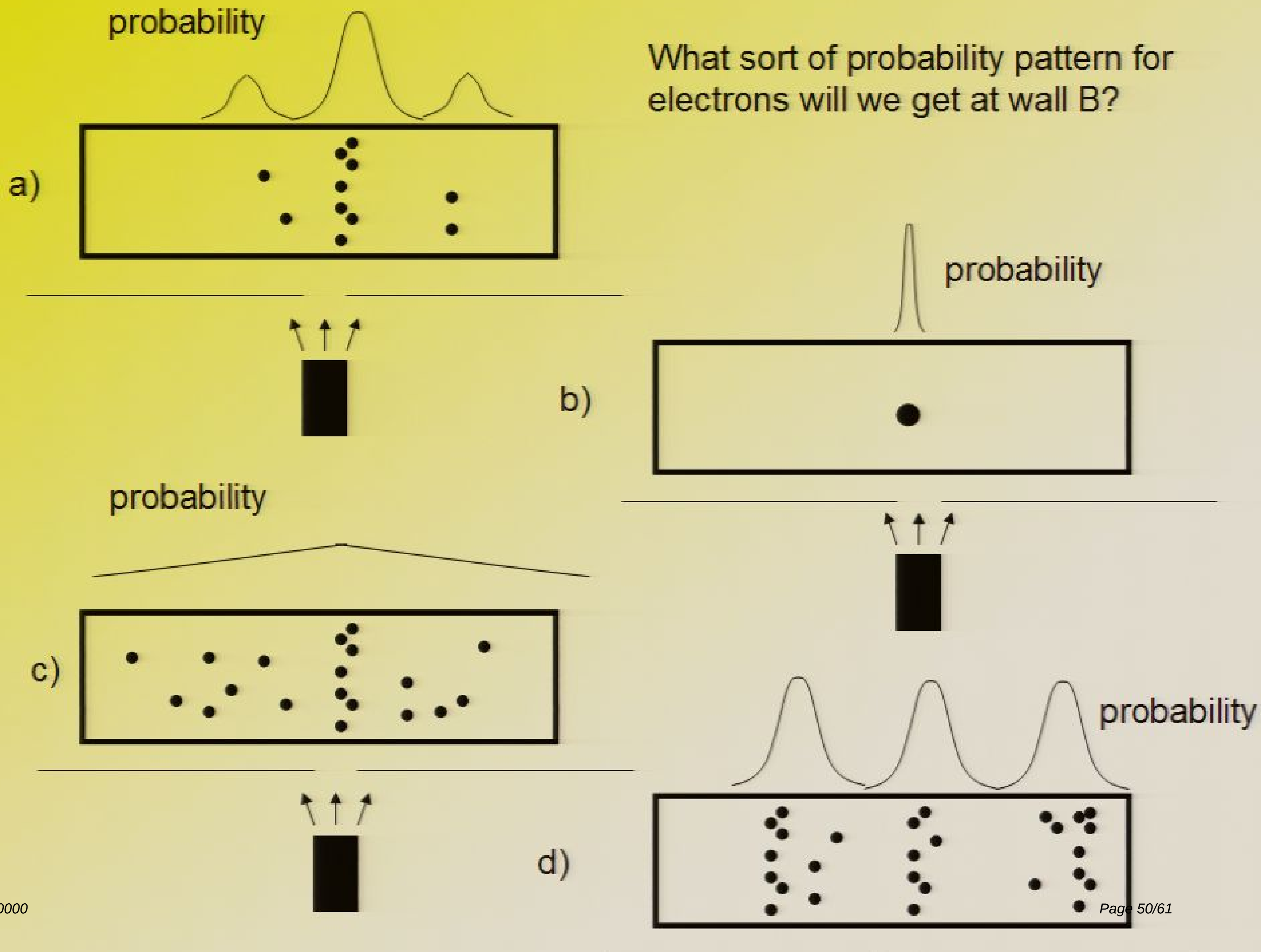

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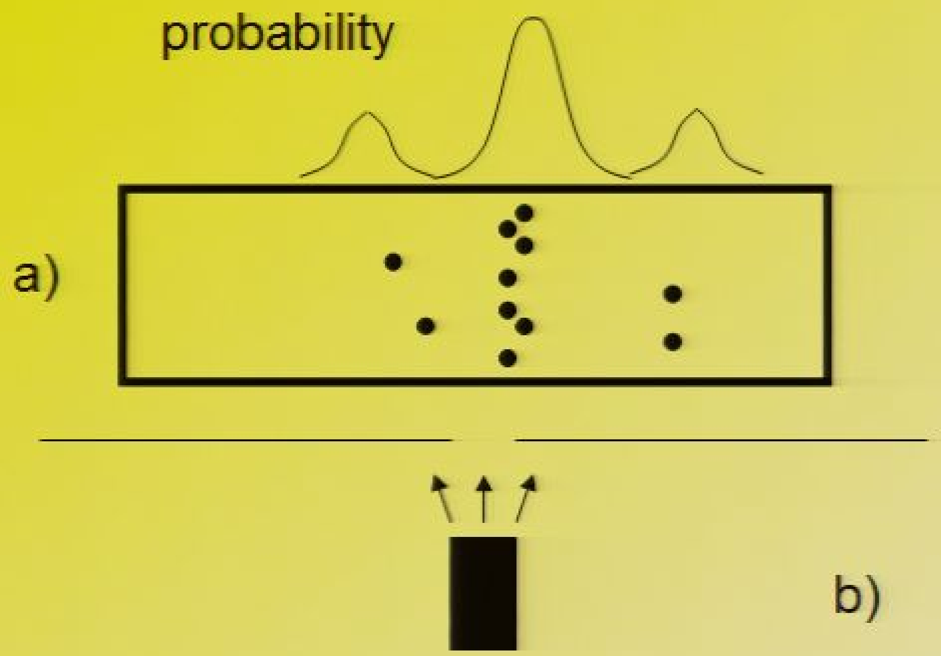

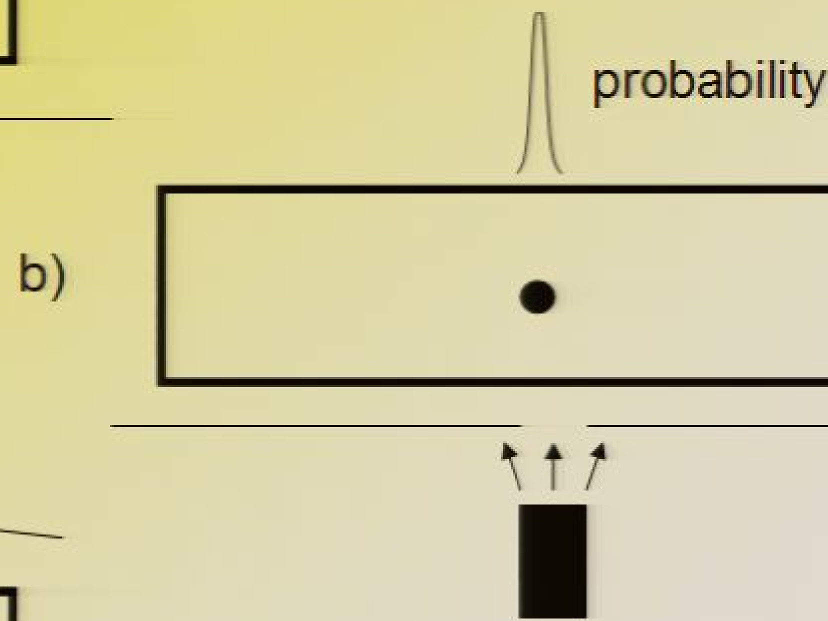

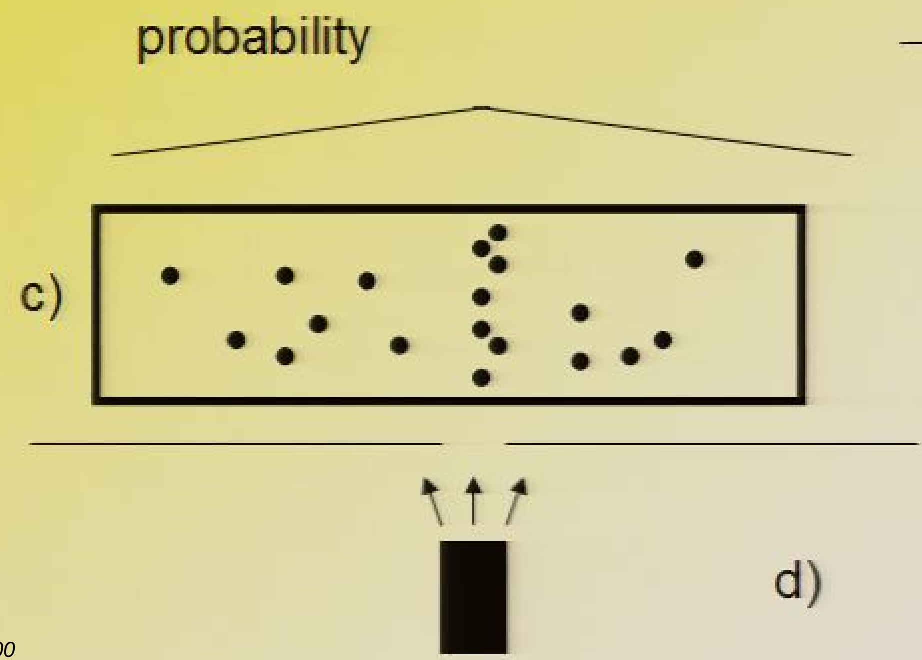

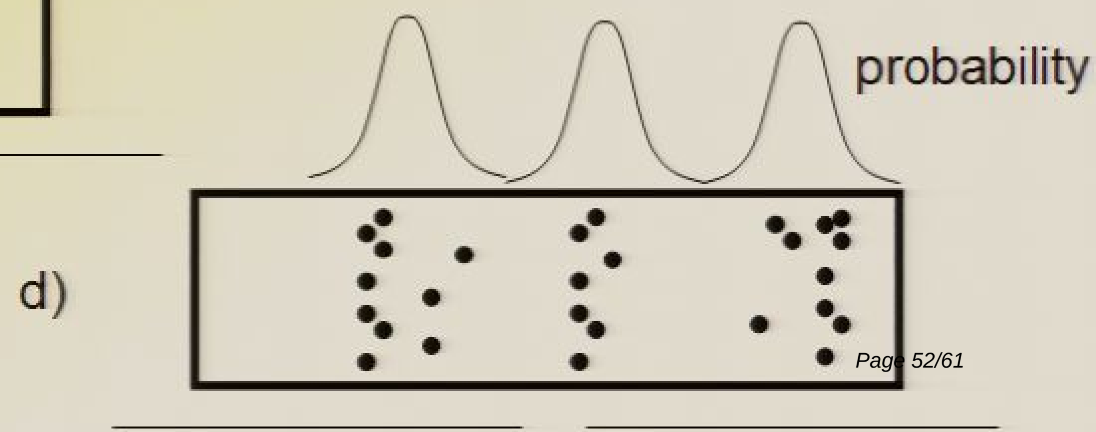

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What happens with electrons?

- Same essential set up. Replace tennis balls by electrons.

- Experiment actually been done.
  (Reference: A. Tonomura, et al., *Demonstration of single-electron buildup of an interference pattern*, Am. J. Phys 57 (2), pp. 117-120 and http://www.hqrd.hitachi.co.jp/em/doubleslit.cfm)

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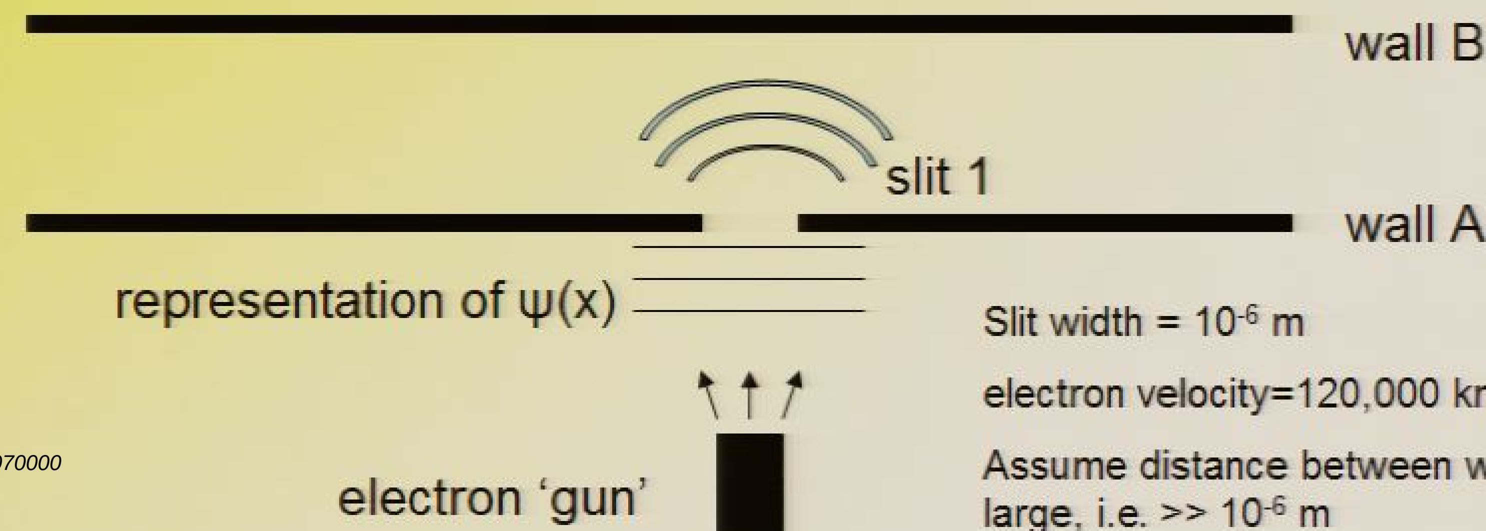

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What happens when both slits are open?

- 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.)

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