

I. Breaking the classical Intuitions:

I.1: Color & Hardness experiment

two Properties of e^-

Color

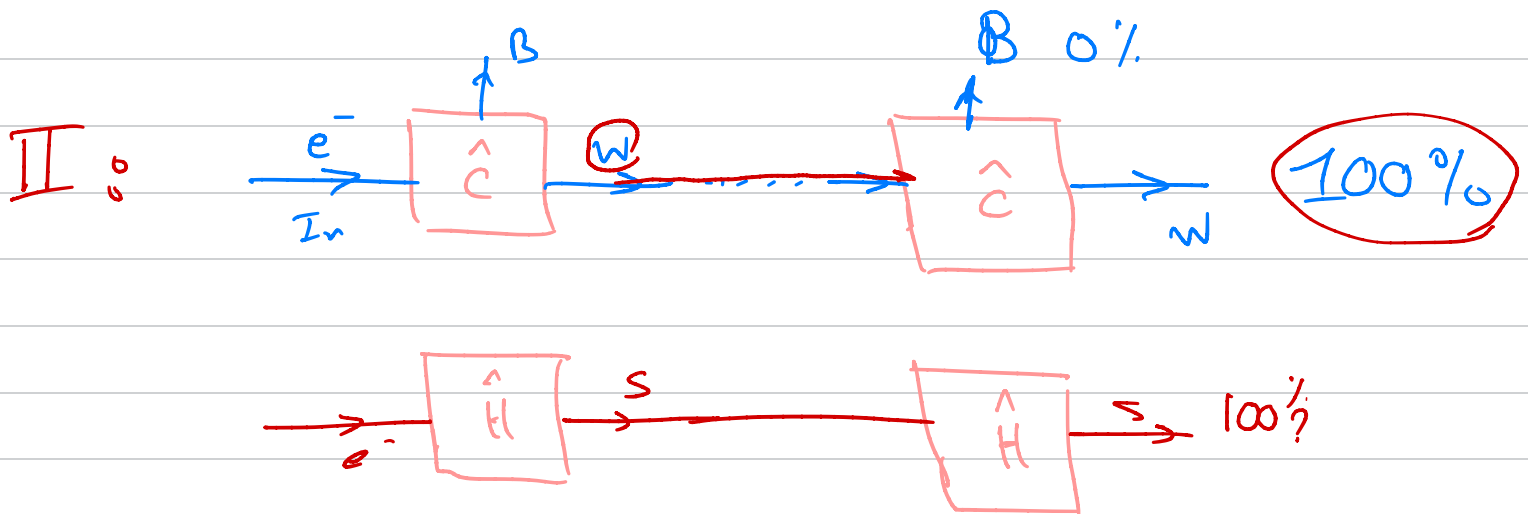
Hardness

empirical fact:

- color $\begin{cases} \text{white} \checkmark \\ \text{Black} \checkmark \end{cases}$
- Hardness $\begin{cases} \text{hard} \checkmark \\ \text{soft} \checkmark \end{cases}$

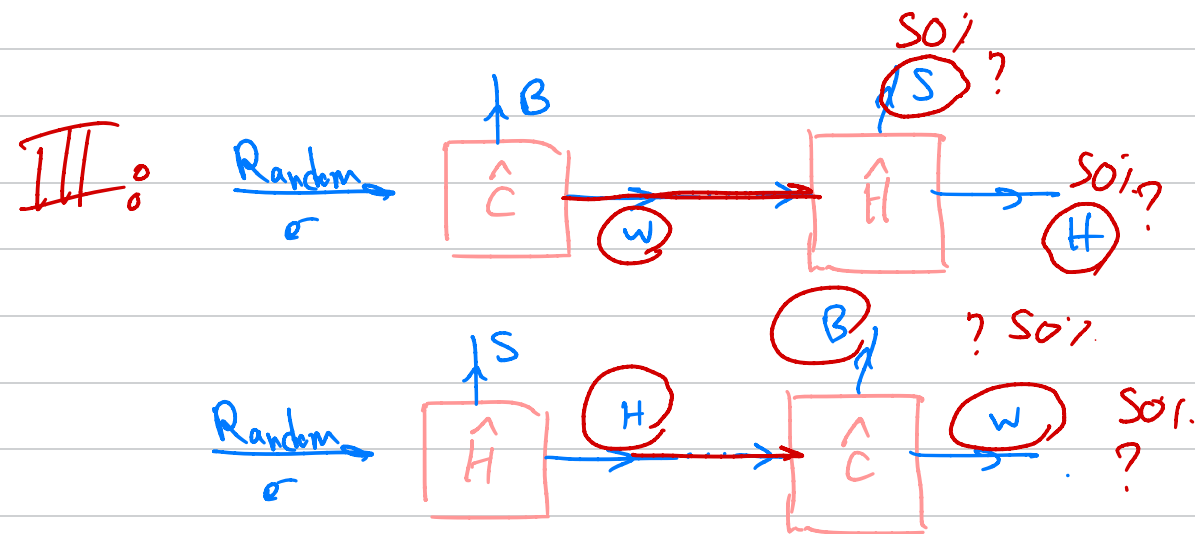


* The Key Property of these boxes: They're repeatable!



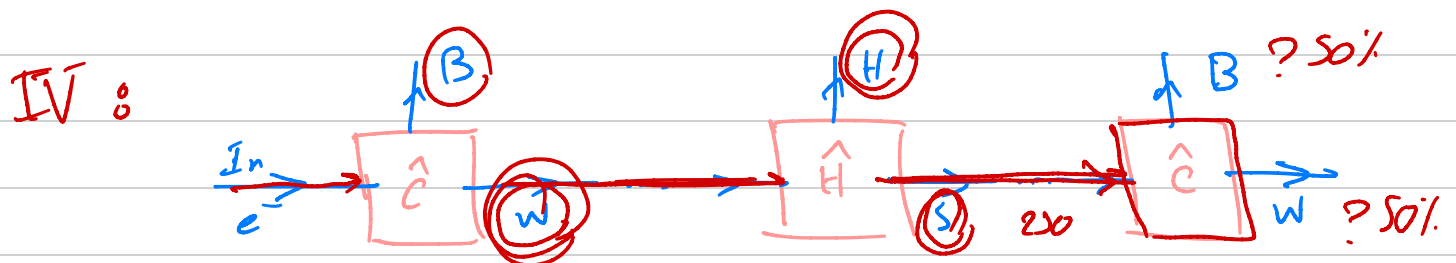
Q: Might the C & H be related? Are they correlated.

Q: suppose e^- is w. determine H?

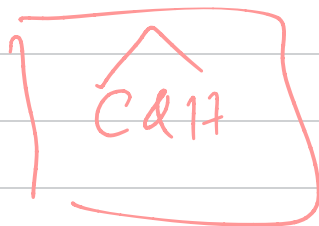


x Independent Properties $\rightarrow$ Not correlated $\rightarrow$ No info ...
Zero Prediction Power

$\boxed{H + C \rightarrow \text{uncorrelated...}}$

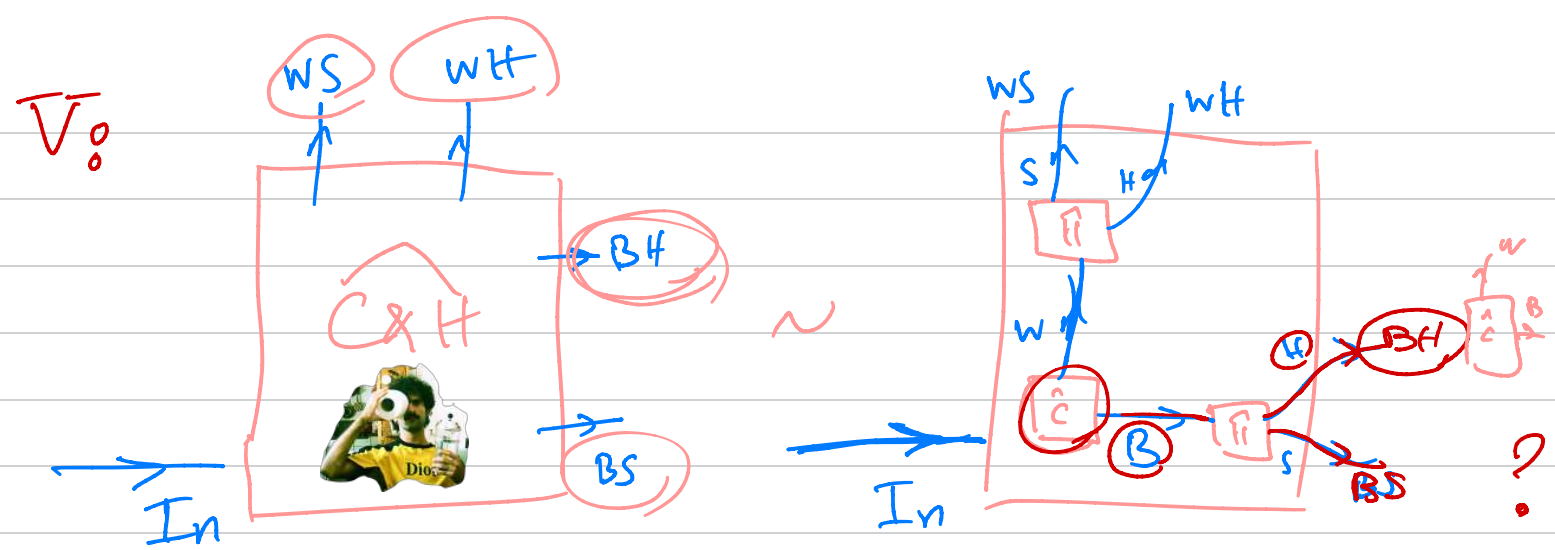


Pred: 100 W%.



Consequences:

Q: Can we fundamentally build a box to simultaneously measure both C & H?



What's the problem with this apparatus?

NOT Persistence! $\rightarrow$ fundamentally disallowed!

This box can not be built! Not because the experiment is crude. $\rightarrow$ Much more fundamental!

! Uncertainty Principle!

$\rightarrow$ There are some observable, measurable properties of a sys, which are incompatible with each other.

Not because you can't know (classical ignorance exp.)!

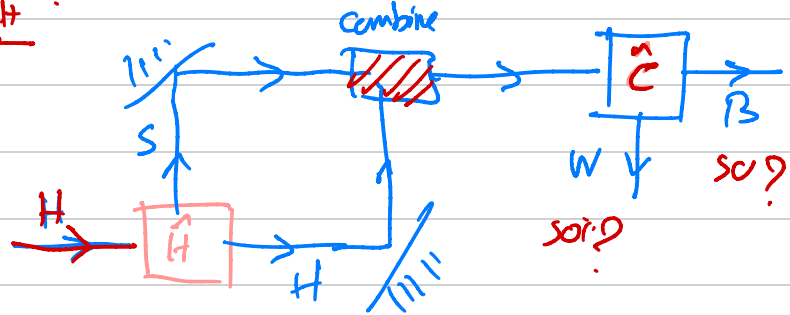
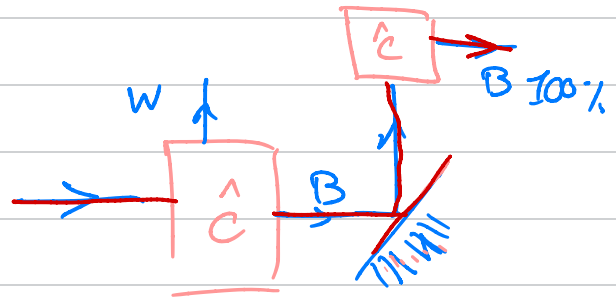
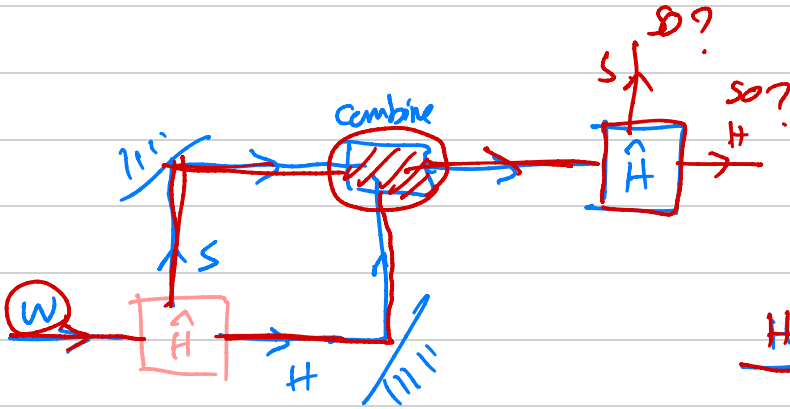
deeper! It can not be white & black simultaneously!



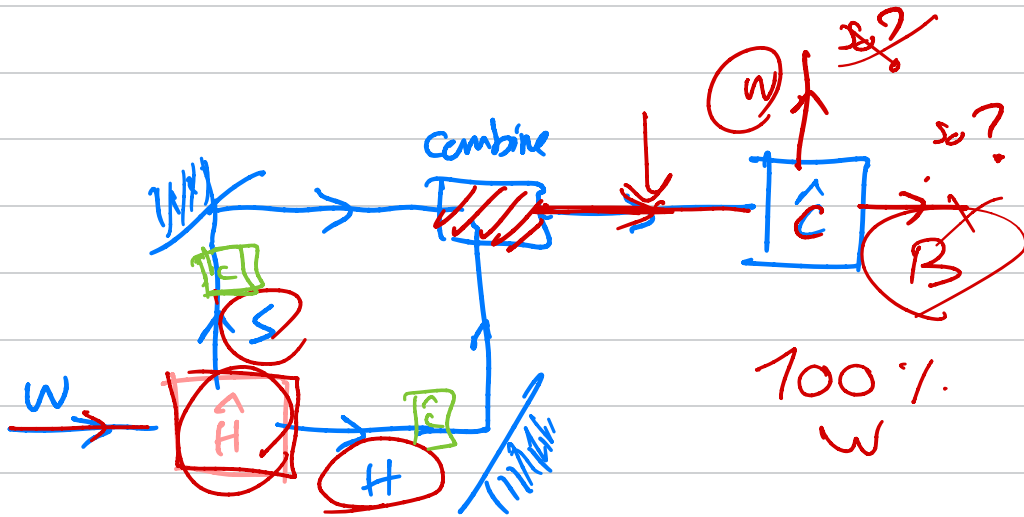
(classical) Ignorance vs. Absence of a definite value

let's go deeper :

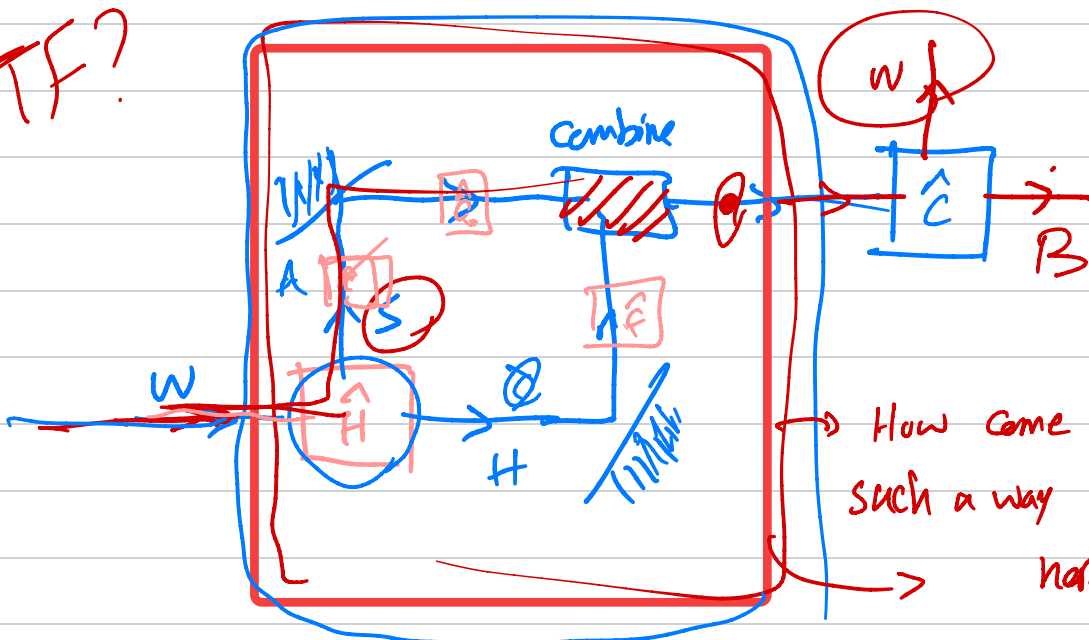
VI: experiments with mirrors :



VII:



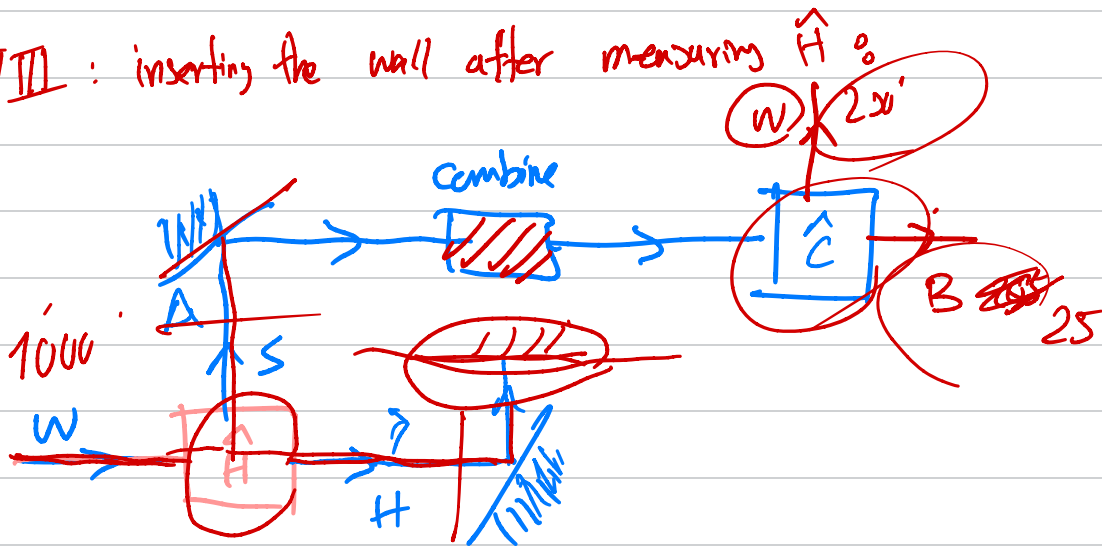
WTF?



How come the result is such a way as nothing happened here

let's alter & perturb the previous experiment to understand what's going on.

VIII: inserting the wall after measuring $\hat{H}$ %



Q: ultimate final Boss Question :

which path did e^- in exp n.VII take?

1. S?

2. H ?

3. None?

40 Both?

Superposition:

$$|H\rangle = \sum a_n |c_n\rangle$$

دانشه احتمال

ماتریس

$$|W_e\rangle = \frac{1}{\sqrt{2}} |H\rangle + \frac{1}{\sqrt{2}} |S\rangle$$

$$|B_e\rangle = \frac{1}{\sqrt{2}} |H\rangle - \frac{1}{\sqrt{2}} |S\rangle$$

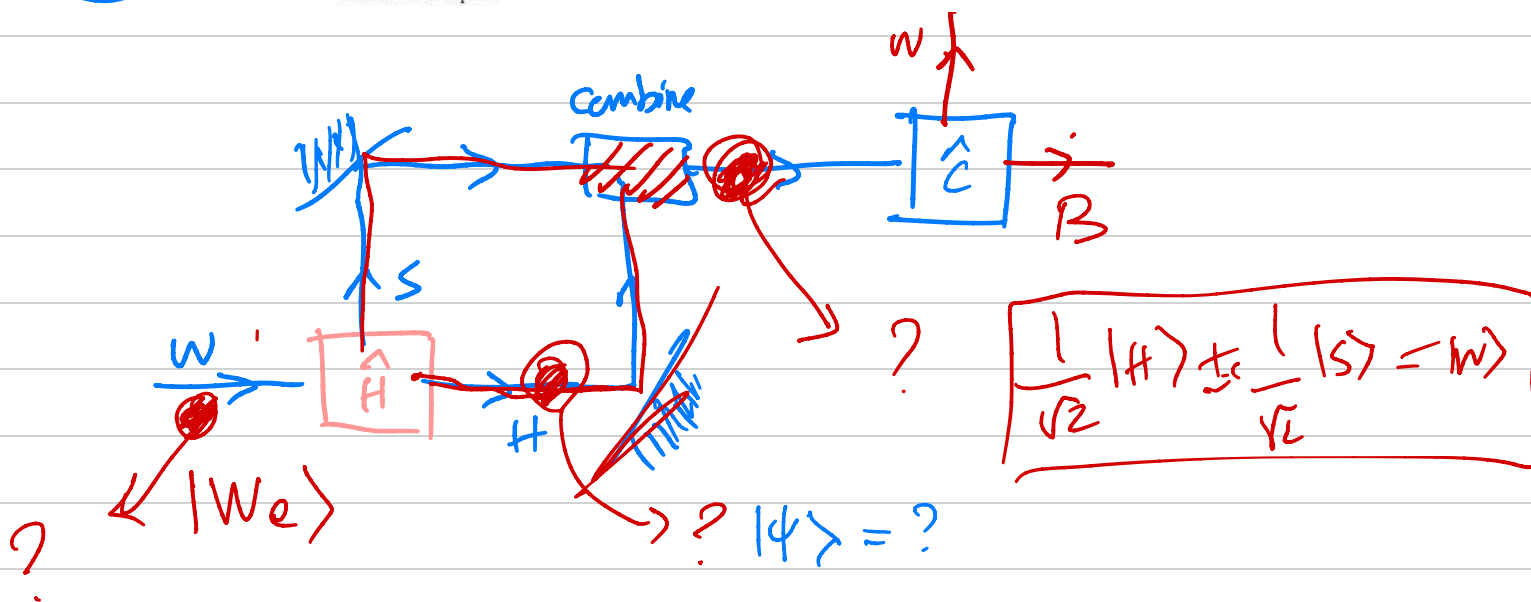
$$|S_e\rangle = \frac{1}{\sqrt{2}} |W\rangle - \frac{1}{\sqrt{2}} |B\rangle$$

$$|H_e\rangle = \frac{1}{\sqrt{2}} |W\rangle + \frac{1}{\sqrt{2}} |B\rangle$$

ایستاده نه هر دو مسیر

او میسره نه خط الکتریک

In the context of our previous experiments, an initially white electron inside the apparatus with all walls out is not hard, not soft, not both, and not neither, but is in a superposition of the states of being hard and soft. This is why we cannot meaningfully say that an electron has given definite values of color and hardness. This is not because our boxes are crude or because we are ignorant (though both may incidentally be true). There is a deeper reason: having a definite value for one property implies not having a definite value but instead being in a superposition of values for the other property. Every electron exits a particular box as having one value or the other for the measured property, but not every electron is in a state of one value or the other for that property. It can be in a superposition of the two values, with the probability that we subsequently measure it to have one value or the other depending on the details of the superposition. For instance, an electron that is white is in an equal superposition of being hard and soft, as the probability of measuring each value of hardness is equal.

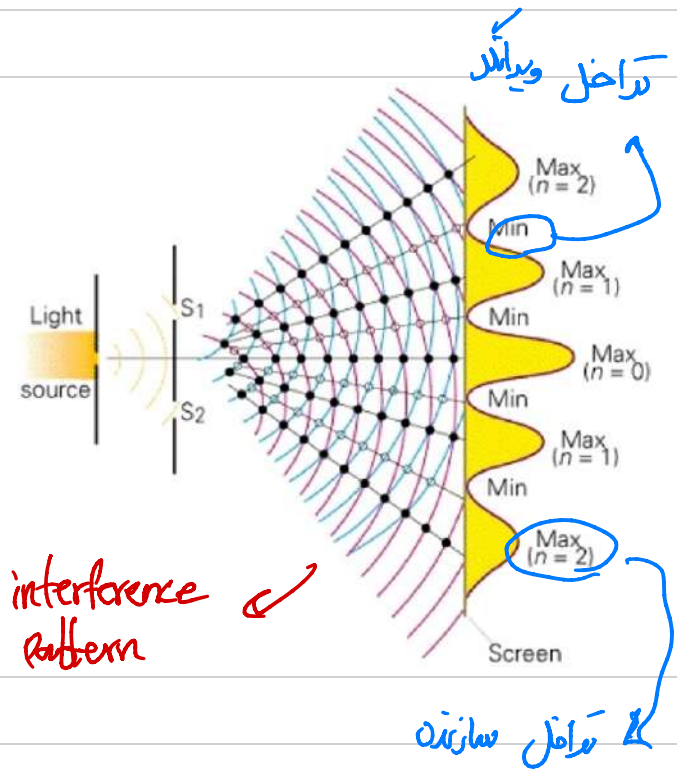
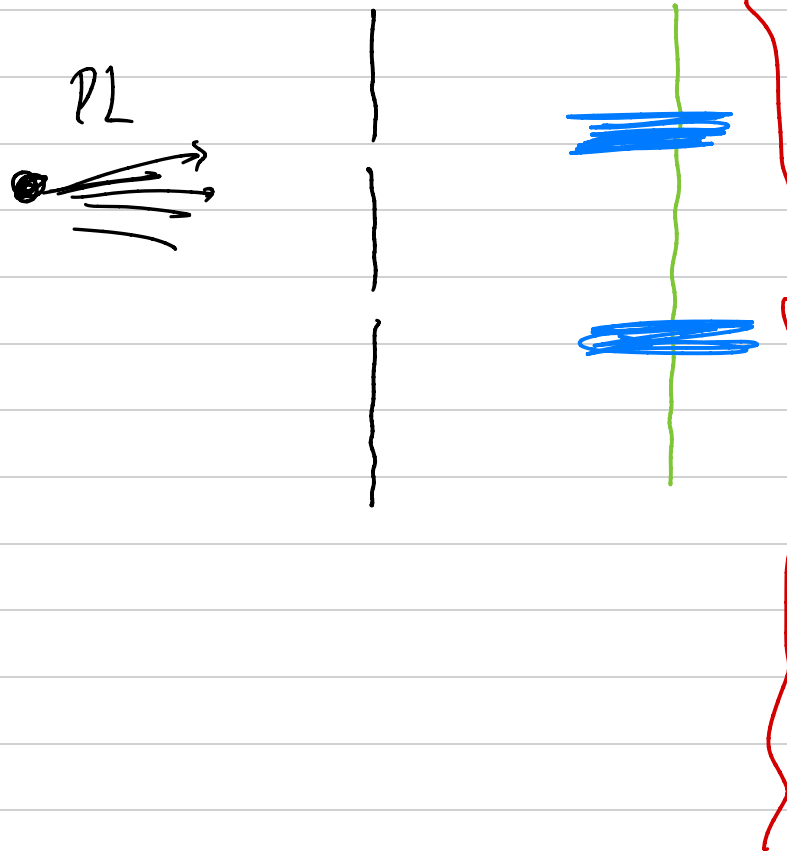
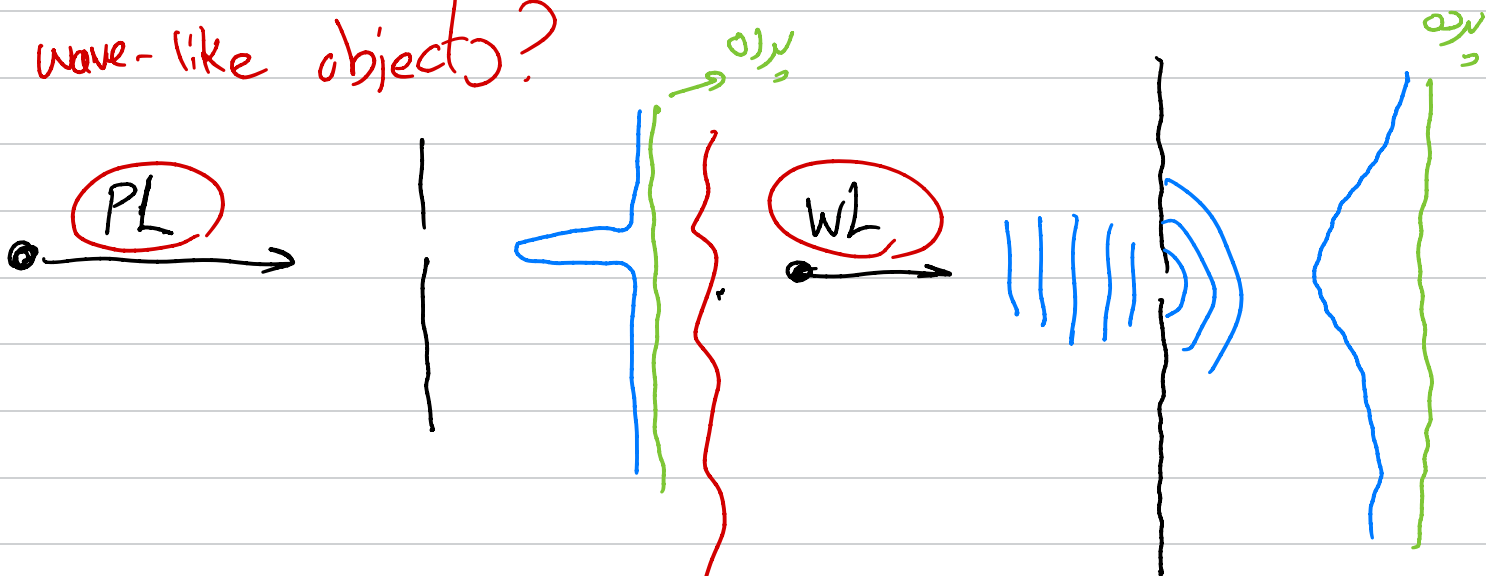


Q: what are the states of e^- in 0 Points?

Q: How can an object, with mass, like e^- behave like this?

Is it really splitting into two? How can a particle split?

Wait! Does e^- behave like particle-like objects or wave-like objects?



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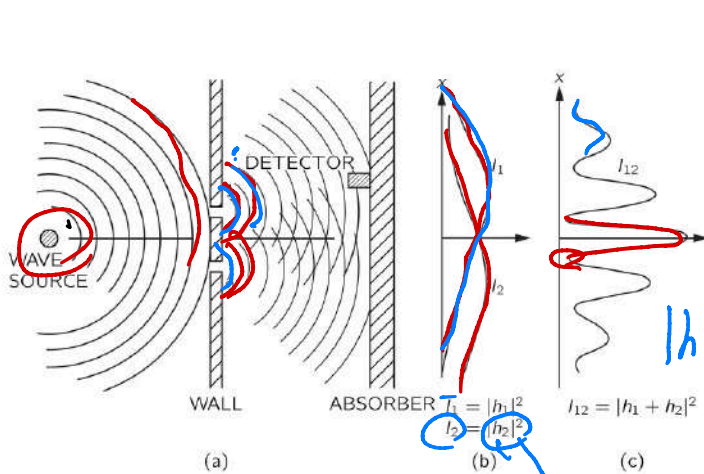
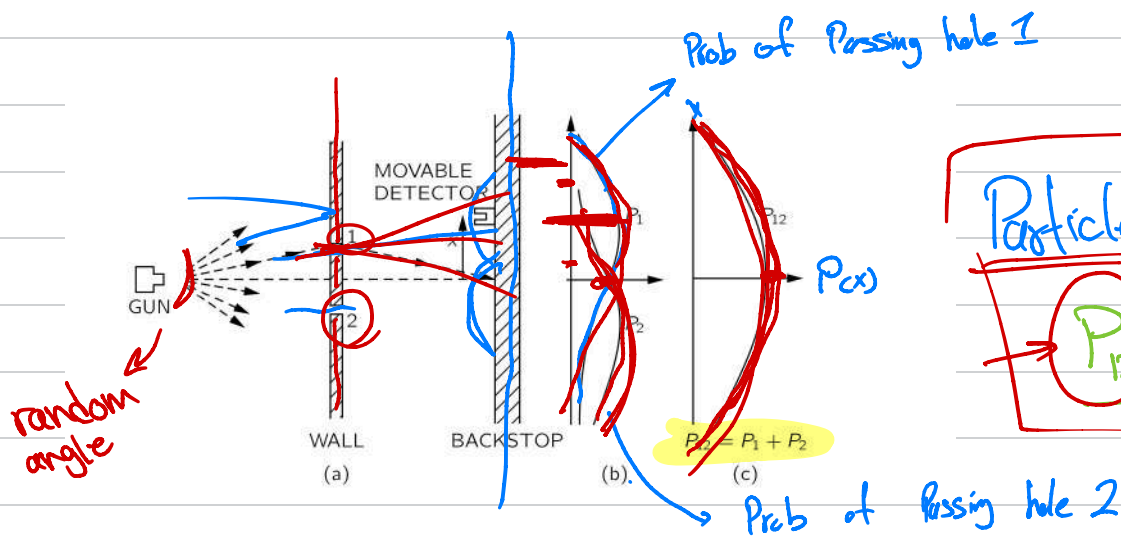
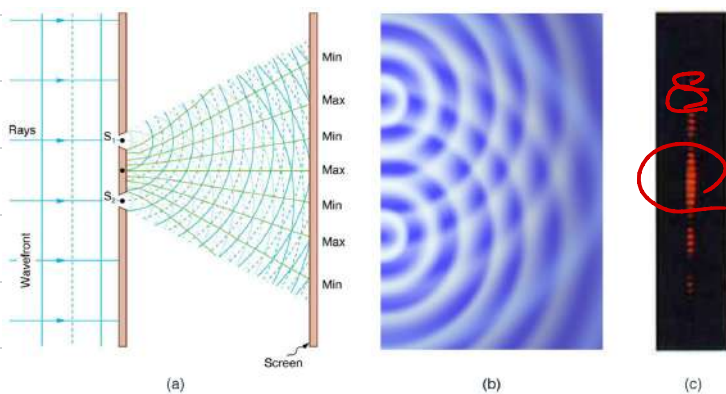


Fig. 1-2. Interference experiment with water waves.

hole 1 intensity h_1

$$I_{12} = |h_1 + h_2|^2 = |h_1|^2 + |h_2|^2 + 2|h_1||h_2|\cos\phi$$

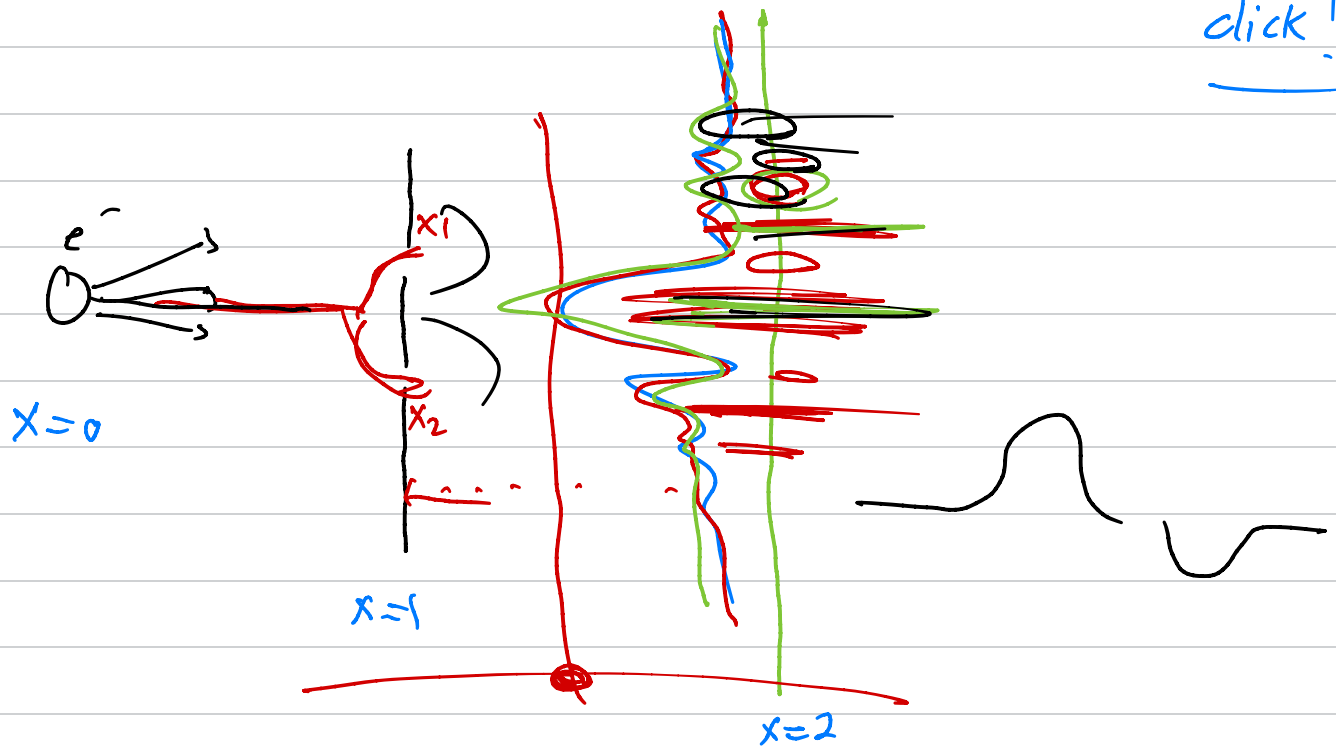
interfering term



Young's 1801 experiment for light

Q: How Does the e^- behave?

click!



How come when we shoot electrons one by one, they create an interference pattern? which path did e^- take?

did they split in half and interfere with themselves?

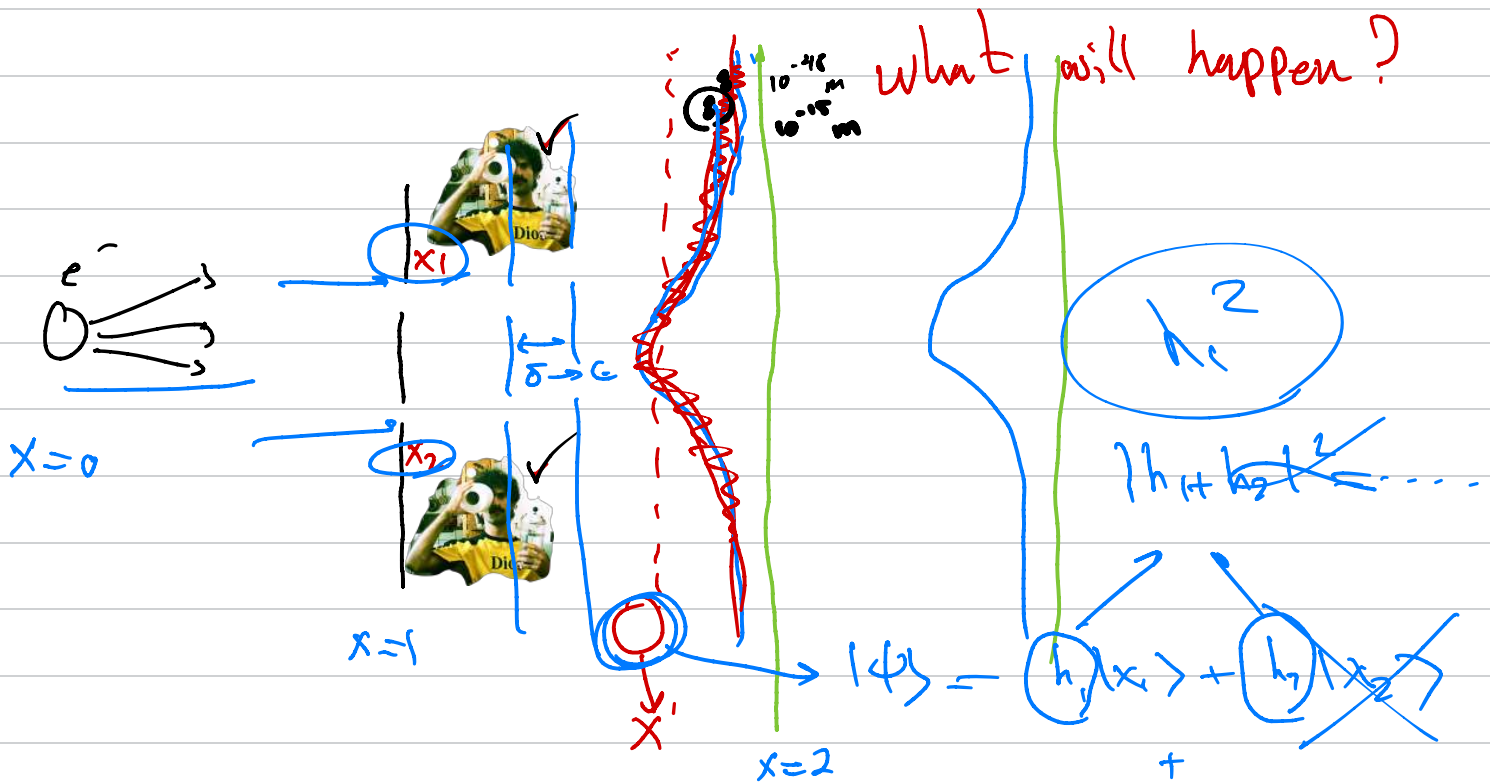
$$|\psi\rangle_{1 \leq x \leq 2} = \underbrace{h_1}_{\text{دالة احتمال موجات } x_1} |x_1\rangle + \underbrace{h_2}_{\text{دالة احتمال موجات } x_2} |x_2\rangle \quad \text{: Superposition}$$

$$P(x)_{x=2} = |\psi(x)|^2_{x=2} = |h_1 + h_2|^2 = \cancel{|h_1|^2} + \cancel{|h_2|^2} + 2|h_1||h_2|\cos\sigma$$

We conclude the following: The electrons arrive in lumps, like particles, and the probability of arrival of these lumps is distributed like the distribution of intensity of a wave. It is in this sense that an electron behaves "sometimes like a particle and sometimes like a wave."

→ wave-particle duality!

Let's disturb & Perturb the double-slit exp for e^- s



Q: what's the state of e^- in $|\psi_{x=x'}\rangle = ?$

Should we talk about disturbance of e^- by γ ?

$\Rightarrow$ uncertainty Principle

$$\Delta p \Delta x \geq \frac{\hbar}{2}$$

$$p = \frac{h}{\lambda}$$

extensive system

$$p = \frac{h}{\lambda} = m \cdot v$$

Non locality & Entanglement & EPR & Bell's theorem

EPR: Quantum's description of the universe is incomplete!

Here's what they meant by "completeness": a description of the world is complete, for them, just in case nothing that's true about the world, nothing that's an "element of the reality" of the world, gets left out of that description.

→ classical examples of coin / gloves : not yet!

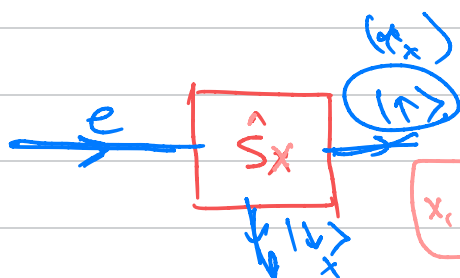
حالت‌ها از همان لحظه اول معلوم بوده، فقط منتظر مشاهده‌شان تا معلوم بشوند

❓ تعریف کوانتوم از وضعیت حالت سیستم چیه؟

Entanglement

همان مثله‌ی رنگ و بوی ← حالا با اسپین :

$\hat{C} \times \hat{H} \longrightarrow \hat{S}_x, \hat{S}_y, \hat{S}_z \longrightarrow$ bigger answers (just like before)
 e^- either goes up or down!



$[S_i, S_j] \neq 0 \rightarrow$ incompatible observables
(just like color & Hardness)

$$|\uparrow_x\rangle = \frac{1}{\sqrt{2}} |\uparrow_z\rangle + \frac{1}{\sqrt{2}} |\downarrow_z\rangle$$

تعریف اسپین از اسپین :

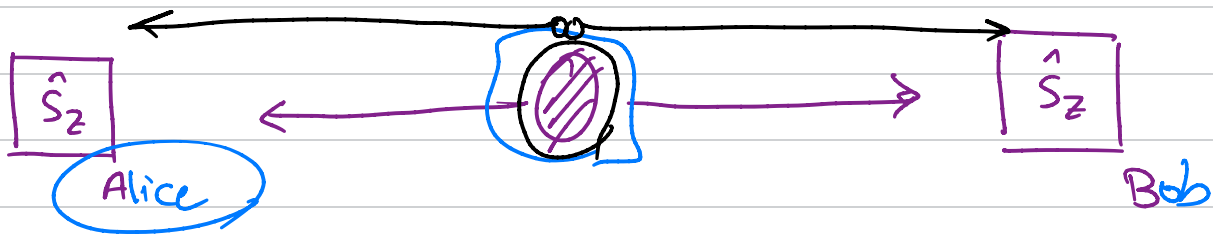
$$|\psi\rangle = \frac{1}{\sqrt{2}} \left[\begin{array}{c} \uparrow_A \downarrow_B \\ \downarrow_A \uparrow_B \end{array} - \begin{array}{c} \downarrow_A \downarrow_B \\ \uparrow_A \uparrow_B \end{array} \right] \rightarrow \text{singlet state}$$

$\vec{S} = 0$
 $S = 1$

what does this state tell us?

Entanglement

① مثال جبهہ دستکش ... کوانٹم میسجنگ؟



* نتیجہ آئیں (باب) تصادفی است ← جبری نہ قطعی است رابطہ بین نتائج موقوف است!

→ Entanglement → Perfectly correlated!

QED →

Classical vs. Quantum world → decoherence

$\uparrow p = h/\lambda \downarrow \Rightarrow$ indistinguishable interference pattern for bullets.

Q: where does the classical world come from?

Q: why we don't see Quantum effects in daily life?

Q: Can we have double-slit exp with humans? why not?

Q: Is brain a quantum system? ...

To talk about in extensive sessions:

1. The measurement Problem

2. The collapse of the wave function:

when does the collapse occur?

- at the level of measurement?
- at the level of consciousness?

Now I want to begin to worry in earnest about whether or not the dynamics says the same thing as the postulate of collapse says about what happens to the state vector of a physical system when the system gets measured. Here's what looked worrisome back in Chapter 2: the dynamics (which is supposed to be about how the state vectors of physical systems evolve in general) is fully deterministic, but the collapse postulate (which is supposed to be about how the state vector of a system evolves when it comes in contact with a measuring device) isn't; and so it isn't clear precisely how the two can be consistent.

3. why $|\psi(x)|^2 = \text{Probability?}$

4. other interpretations of QM:

Bohm's (duality?)

- many-world inter

• Feynman's Integral

Resource:

- Feynman's Lecture on Quantum Mechanics:

https://www.feynmanlectures.caltech.edu/III_01.html

- MIT Lectures on Quantum Mechanics (Adams)

<https://ocw.mit.edu/courses/8-04-quantum-physics-i-spring-2013/pages/lecture-notes/>

Quantum Mechanics and Experience (David Z Albert)

- My lectures for Quantum Mechanics II course, when I was cool enough that could teach QM!