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$$\begin{aligned}B^3 &= CD + DA \\B^3 &= (D - CSIN B) \\B^3 &= D^2 - 3A \cos B^2 + A \sin B \\B^3 &= D^2 - 4A \cos B^3 + C \sin B \\B^3 &= C^3 - A^2 - 3 \cos B\end{aligned}$$

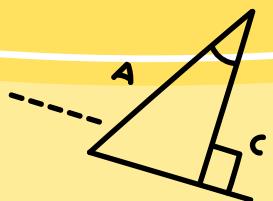
$$x_2^4 + x_3^2 = (x_2 + x_3)^2$$

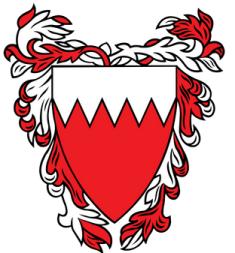


Quantum tunneling

"Inside the tunnel"

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PHYCS326





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Tunnels time mystery: lesson path

introduction

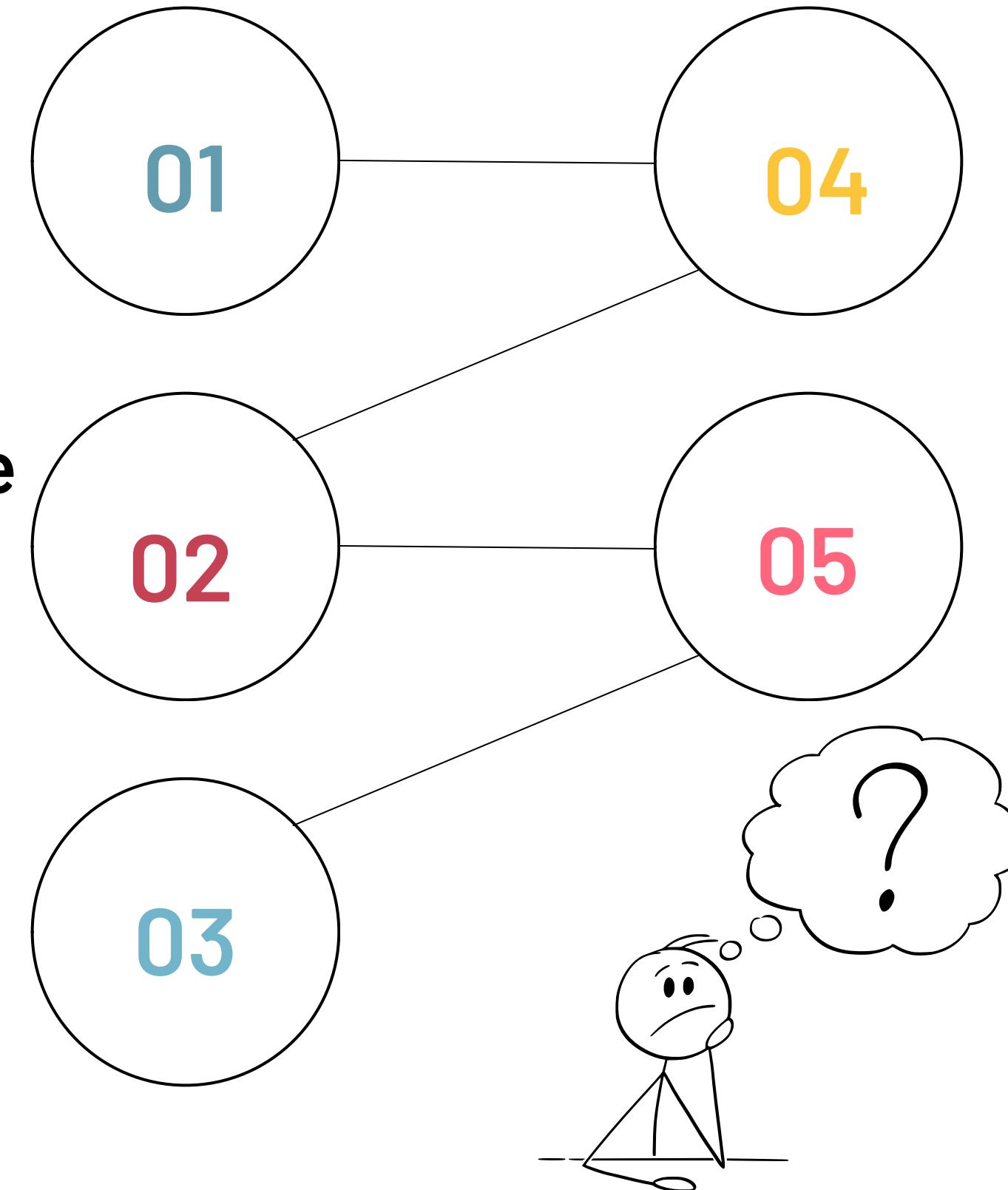
What is quantum tunneling effect?

Uncertainty principle

Why is that?

Theoretical

what are the interpretations for the tunneling time?



Hartman effect

Can the particle increase in their speed through this effect?

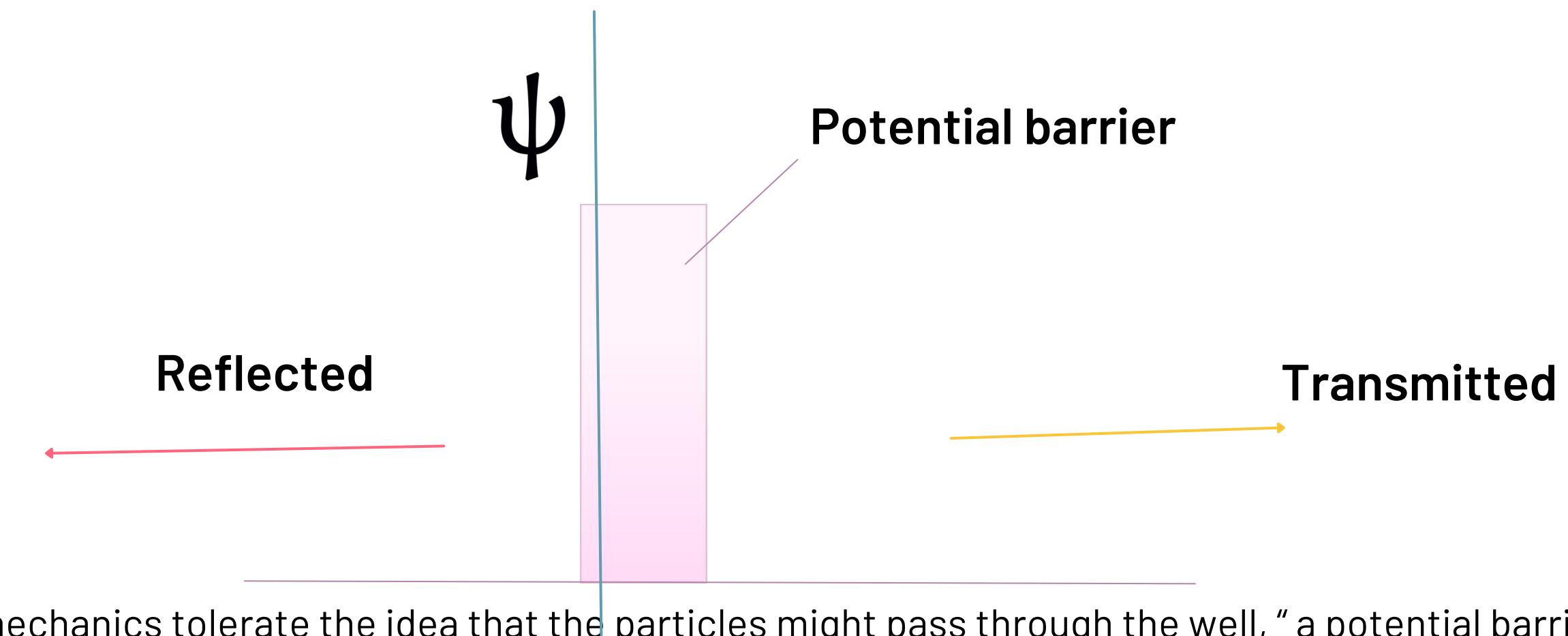
Experiment

How can we measure tunneling time by experiments?

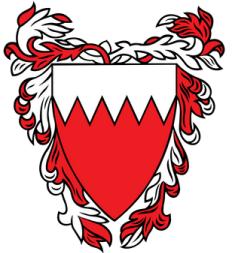


Introduction

- The tunnel effect is a quantum phenomena that is forbidden in classicle system, and detectable only for low-mass quantum objects such as the particles, when it goes through a microscopically narrow barrier:



- In fact. Quantum mechanics tolerate the idea that the particles might pass through the well, "a potential barrier", as the quantum object motion described by the wave function. In fact, mathematically it showed that the wave function decreased exponentially inside the barrier, and the probability of finding the electron outside the barrier is non-zero



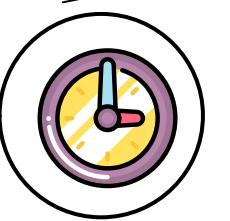
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Uncertainty Principle

We tolerate this science-fiction idea because of the highly-respected **Heisenberg uncertainty principle**, the more accurate we know about any observable that

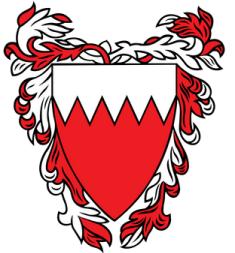
$$\Delta x \Delta p \geq \frac{\hbar}{2}$$



Uncertainty in position

Indeed, we cannot know for sure where is the particle, the probability of finding it outside the barrier might be **0.0000000000000001**, but still, it's not zero!





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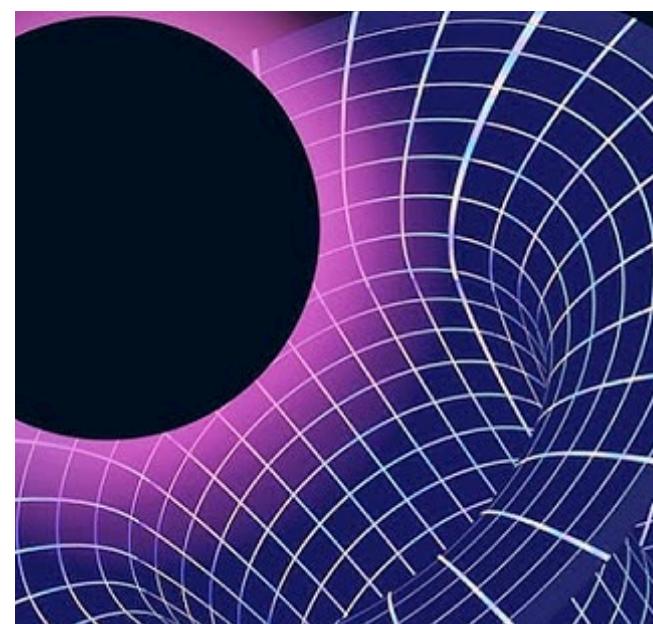
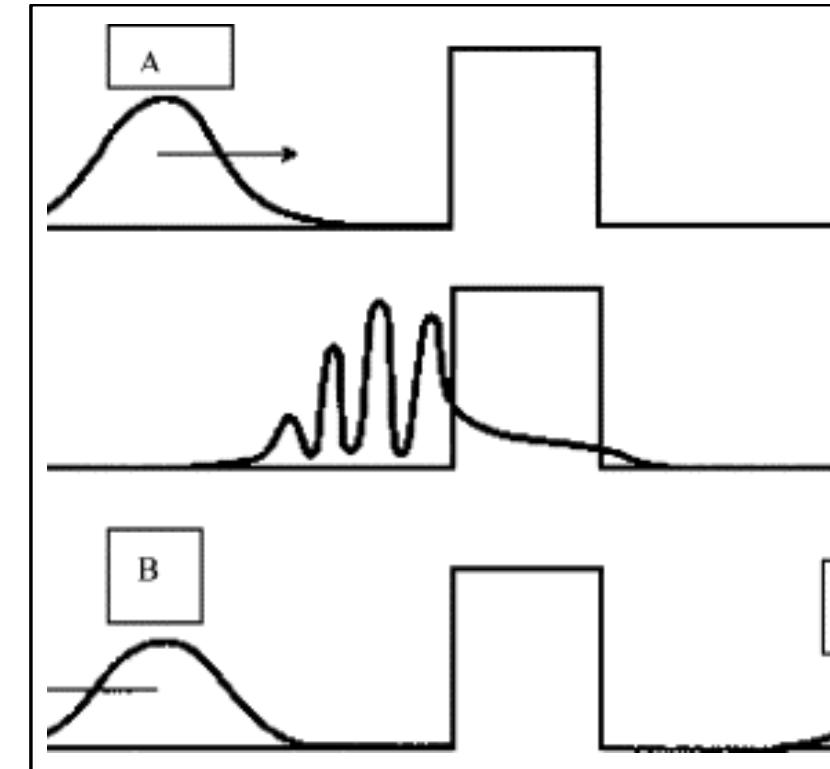
hartmen effect

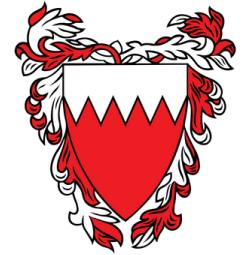
In 1962..

It was consider theoritcally and experimently that the tunneling time is likely to be indipendent of the barrier, which is so called Hartmen effect- apperently named after the one who discovered it...

this effect permit it to travel more than the speed of light!

It was the essintail mystery of the tunneling time that remains controversy for decades.





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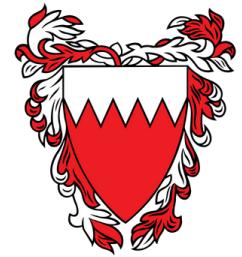
But wait..



DOES THIS
RESULT VIOLET
CASUALITY?

Does that mean we break
the holy theory of special
relativity?

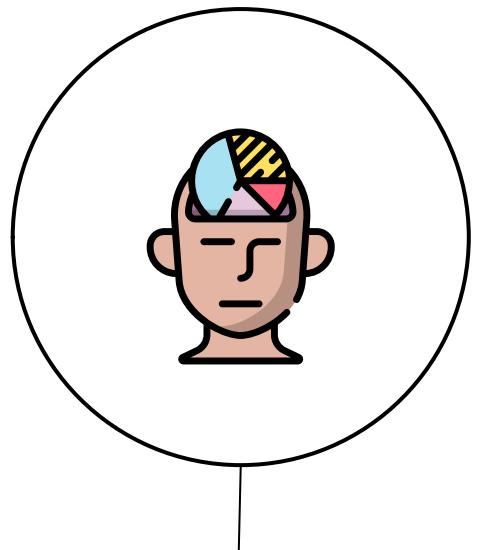
Well, the idea that
transmitted wave function
can be superluminal has
been taken seriously, but
let's discuss the context:



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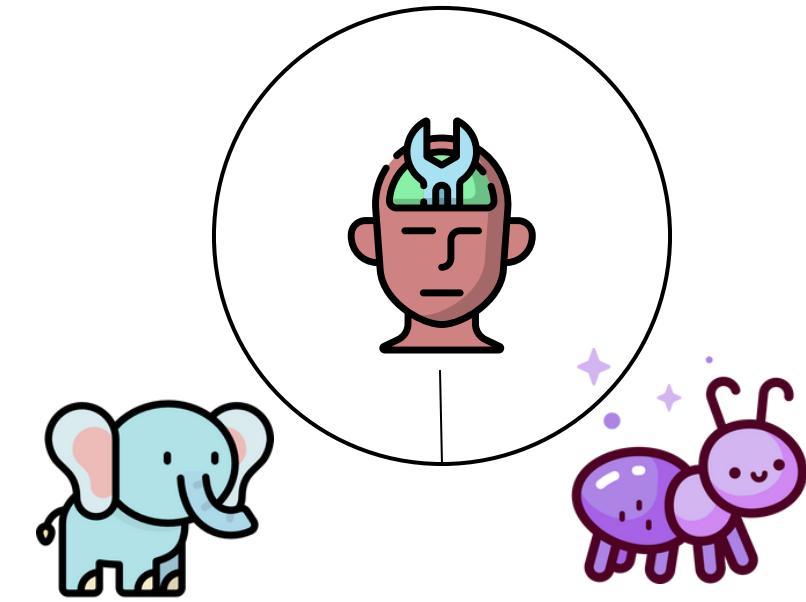


Three different interpretation regarding hartman effect



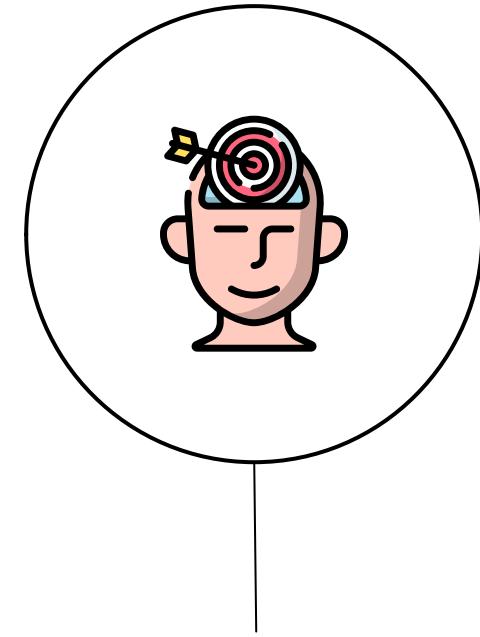
Nimtz claim 1 Venus

Superluminality signal transmissn could happen,
the authers did.'t agree with him though.



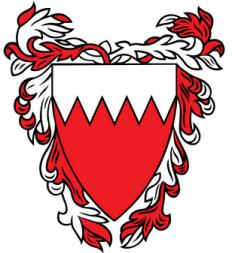
claim 2 Wave deformation

The wave pocket is re-shaped, it's like it get damaged during the tunneling process. Hence, the input and output signals are note the same



Winful claim 3 'you guys are wrong'

'The tunneling the time'
doesn't necceserly describes
the 'flight time'. Frankly, I
don't see the tunneling time
that you are obssed with as a
meangful quantity

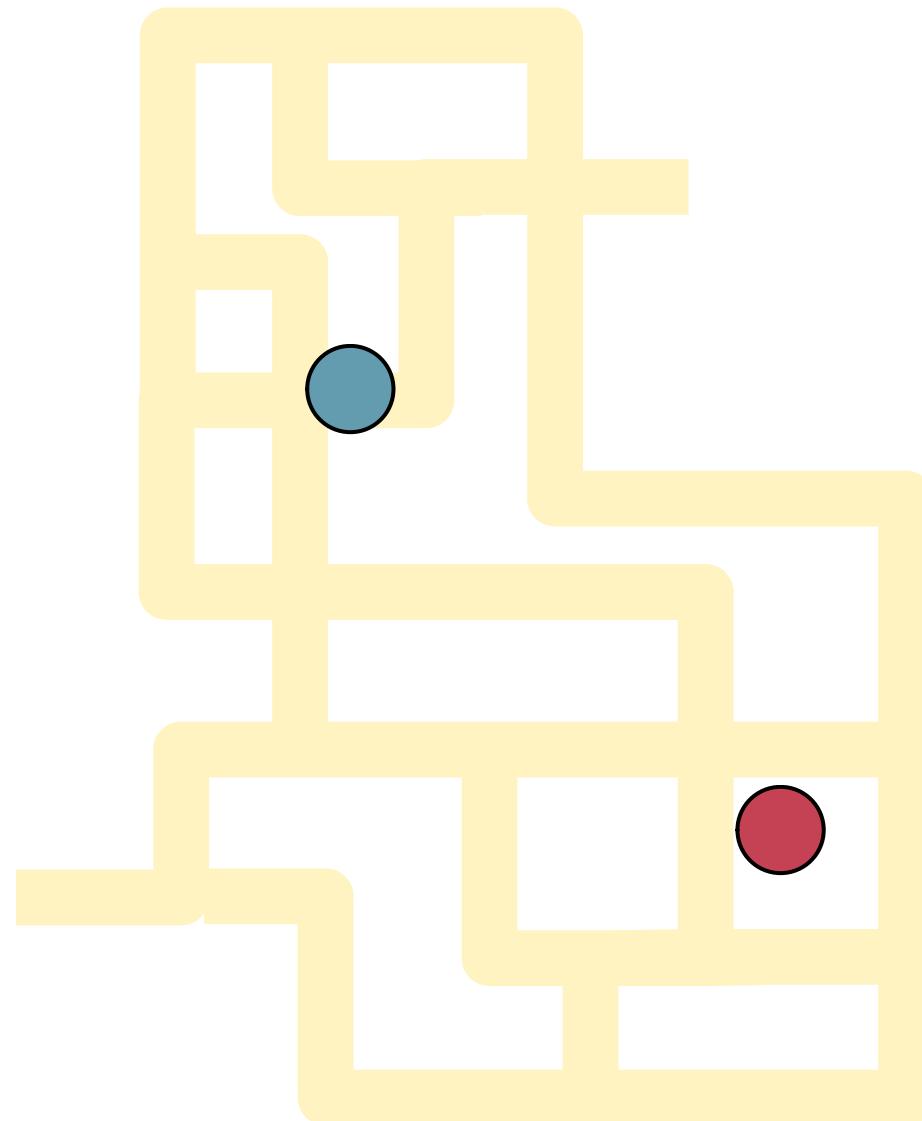


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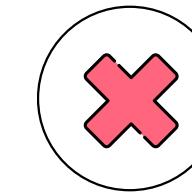
oh..maybe we just need to ask better question?

Can we measure the
tunnels time actually?



01

A recent published study adopted
this idea, they used Dirac equations



02

So instead of thinking of the messy
'tunnels time' idea, let's consider another
question:



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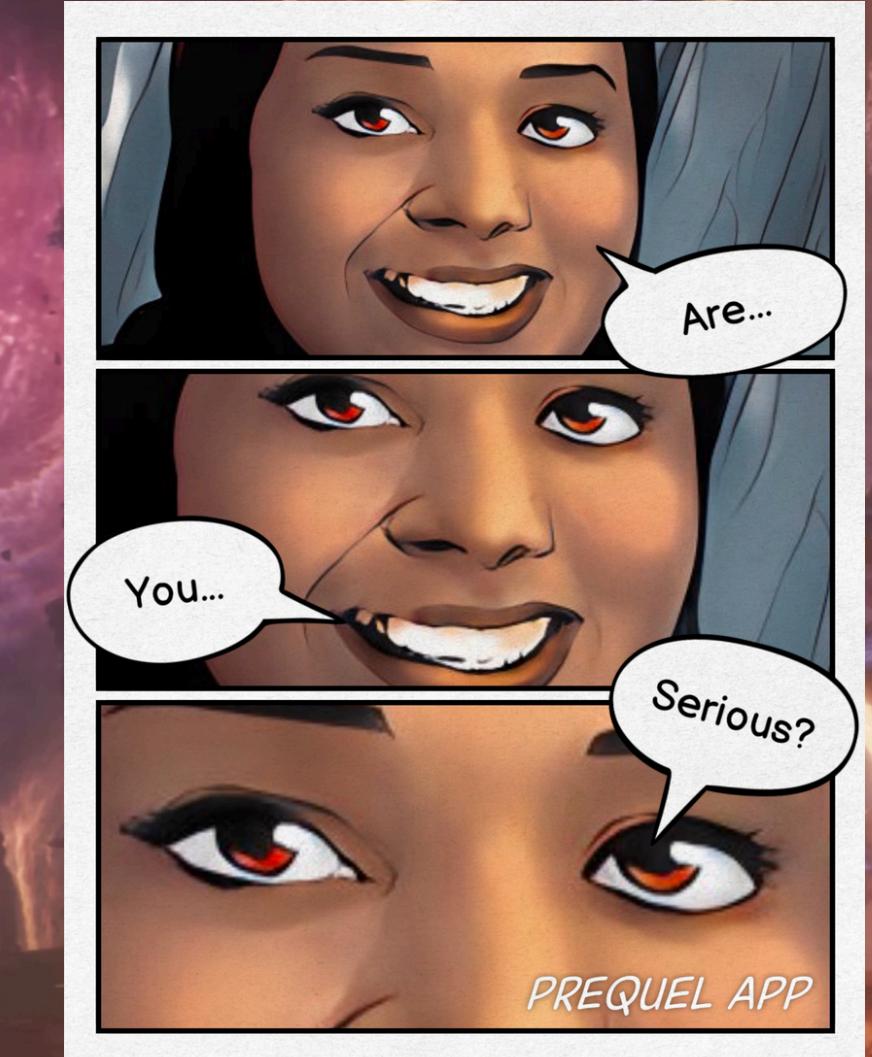


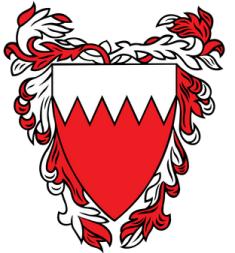
Though experiment which is the fastest why??



In quantum realm
There is obstacles everywhere, lets call them a potential barrier:

- I can only send signals via particles
- I'm lost and I can't reach my friend.. which is faster to throw particles in a free space or through a barrier?? I don't know I did both.





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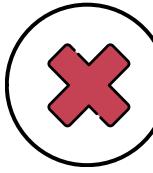


The others intrepretation



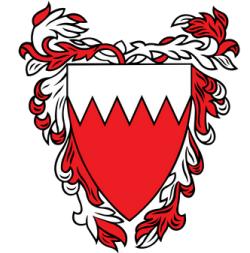
BuT...

Still, we manifest the Superluminal time, for a discrete circumstances that doesn't count for the Superluminal signal. Yet we can't 'digestive' the idea of cutting off the wave function. - Okey I'm paraphrasing -



They rejected the previous interpretation, their results showed similarity to the entering state.

The only 'shaping' was with the amplitude of the wave function, due to the low transmission probability.



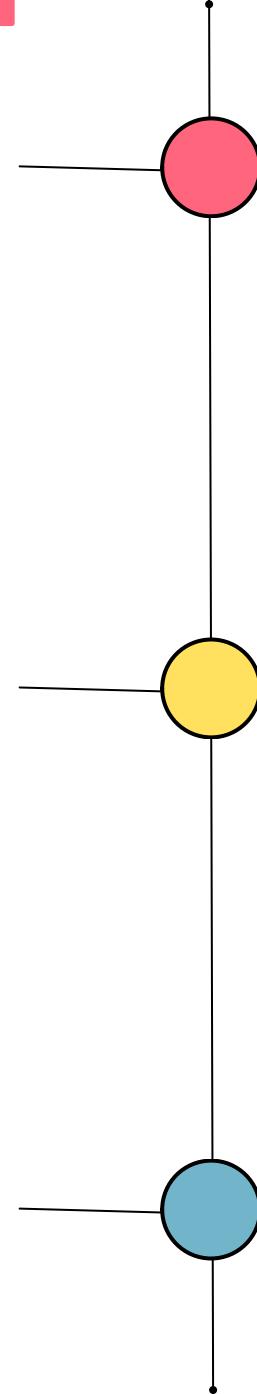
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findings of the thought experiment

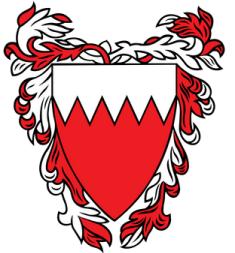
It was found that the peak of the tunneling particle appeared at the screen earlier than the free particle!.

So the tunneling particle is superluminal in time?



Well..

In fact, this count just for the particle that could make it through the barrier, and a minuscule number of particles does while the rest are reflected! I kept throwing particles on my friend.. The probability that she received a free particle is more than the transmitted ones!



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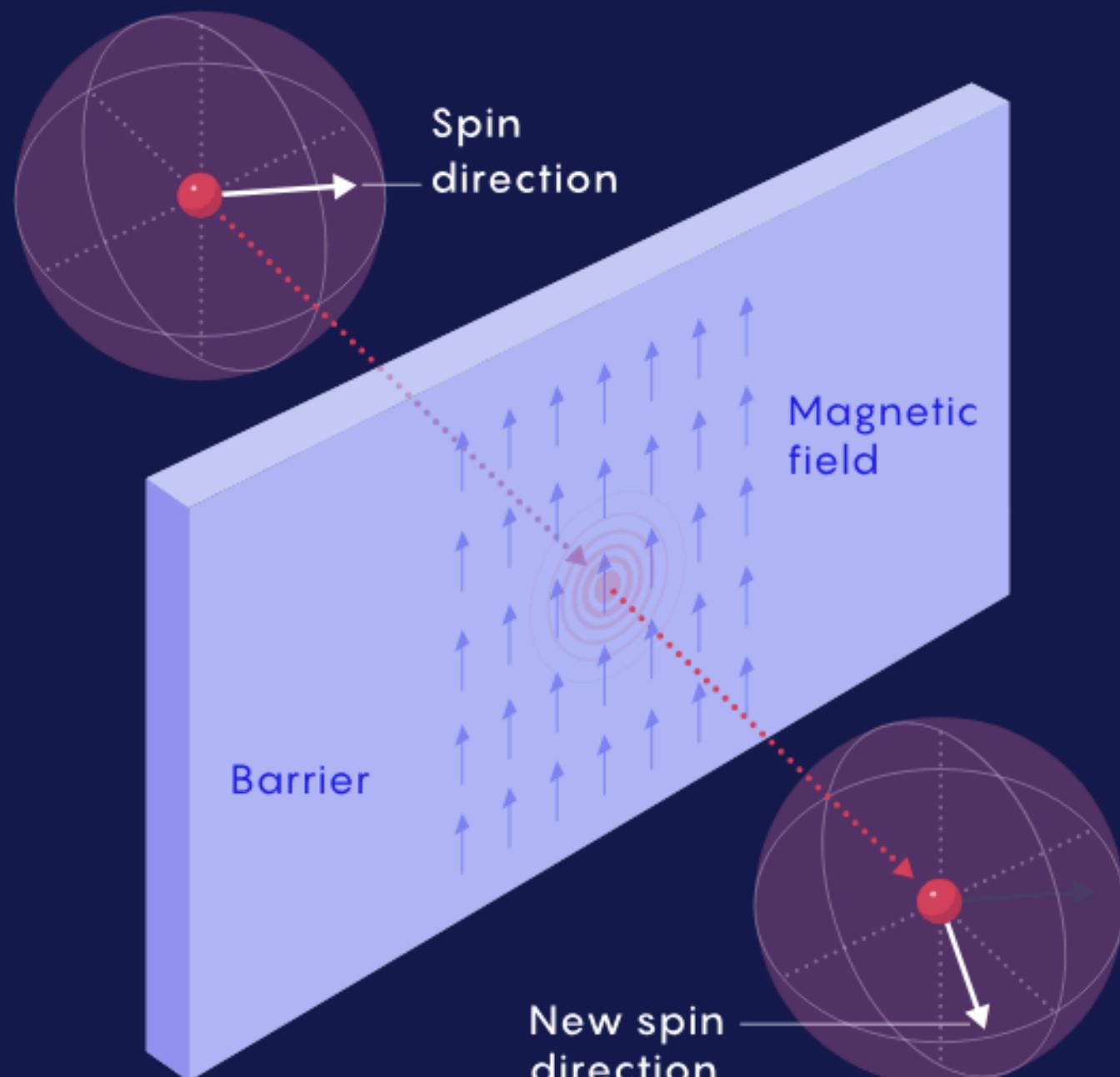


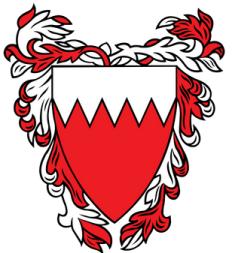
what about experiments?

Quantum as a stop watch

In 2020, Nature magazine published a paper that measured the tunneling time using a quantum tool!

Walk Around the Clock
As a rubidium atom passes through a magnetized barrier, its internal spin will rotate, or precess. Physicists measure the amount of precession to infer how long the atom spent inside the barrier.





What about experiment?

01

An ultracold rubidium atoms was objected to a laser field, as it spread at a relatively small area..

03

Experimentally, it was found that the spin of the particle was altered by the magnetic field of the barrier

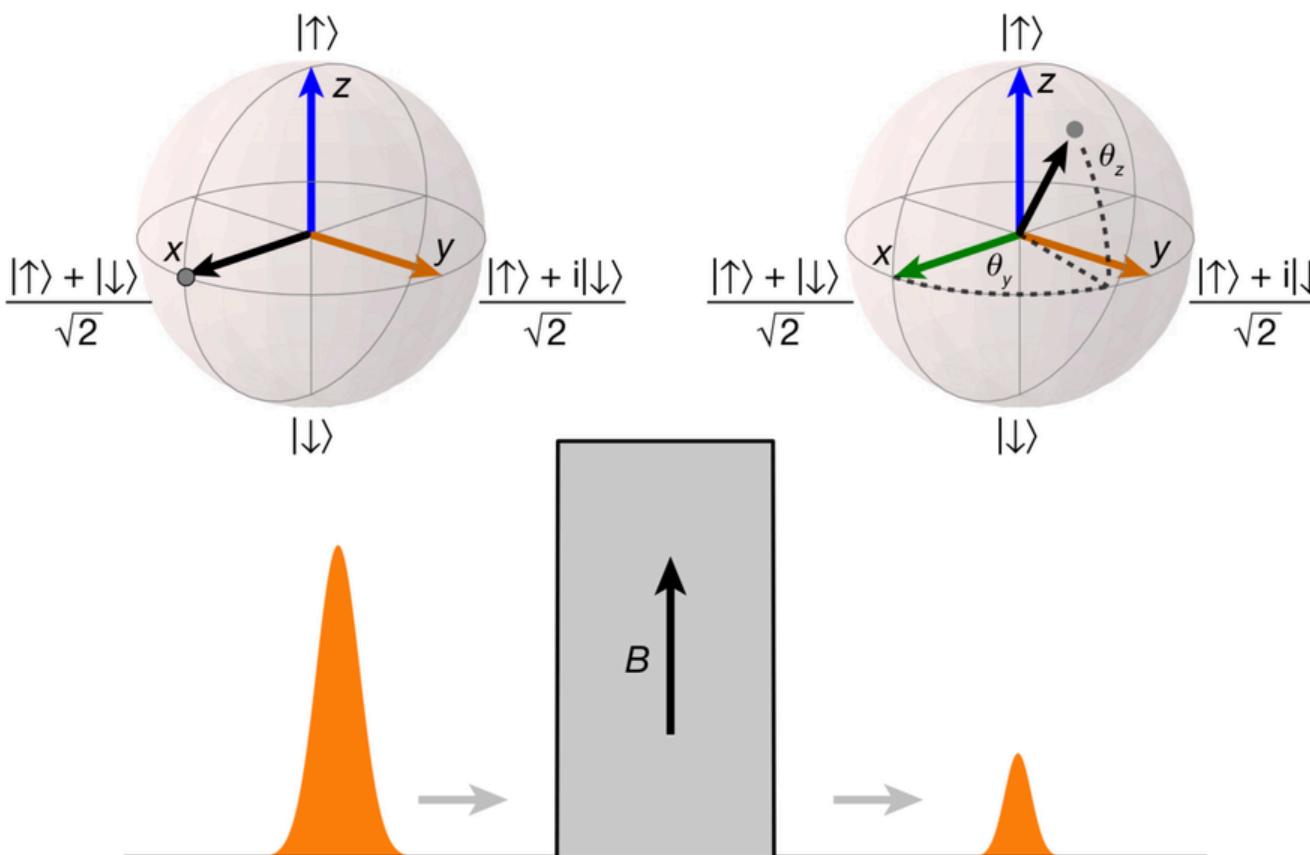


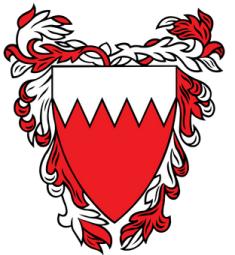
Fig. 1 | Larmor clock. A weak magnetic field B pointing in the z direction is localized inside the potential barrier. Reference: Natural magazine "Measurement of the time spent by a tunnelling atom within the barrier region"

02

The field acts as a barrier, as a particle bounced off the barrier and some of them could penetrate .

04

Their results agreed with the theoretical calculations!

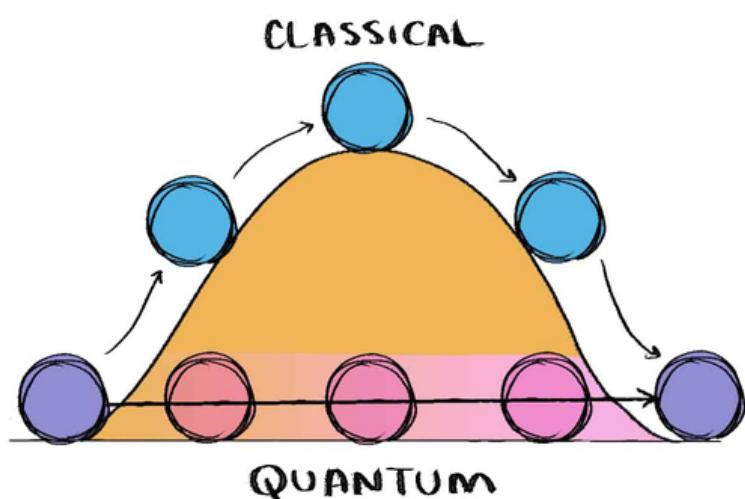


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Einestine you can chill>>

01

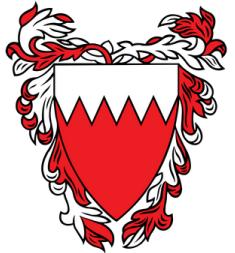
when its coms to speed
of light limit, special
relativity always win.



02

We still got a wide
domain of researchs!





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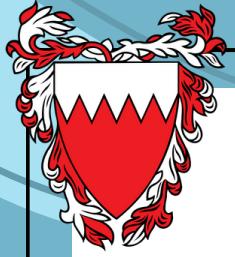
Conclusion

Experimental work succeeded providing a new tool for measuring time for quantum objects!

Quantum tunneling is one of the most extreme phenomena in quantum mechanics that has a lot of applications and aspects that are still under research.

Quantum tunneling time is a contentious concept that the physics were fighting about,

Theoretical paper counted for the superluminal time particle, but the interpretation were not that sufficient.



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