



Physics

<https://www.2pennyphysics.it/category/school-labhome/>

# Two-penny Physics.



**Politecnico  
di Torino**

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# Agenda

## Mechanics

- Linear momentum conservation in 2D
- From the classical experiment to modern physics

## Geometrical Optics

- Let's shed some light on coffee

## Quantum Mechanics

- Quantum mechanics with a straw



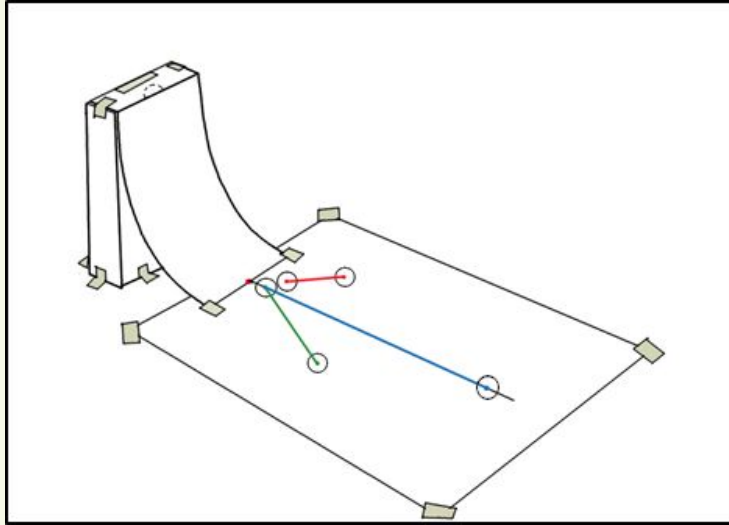
Physics

# Mechanics



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# Linear momentum conservation in 2D



Low-cost apparatus to explore the physics of collisions.

# Presentation of the activity & Aims



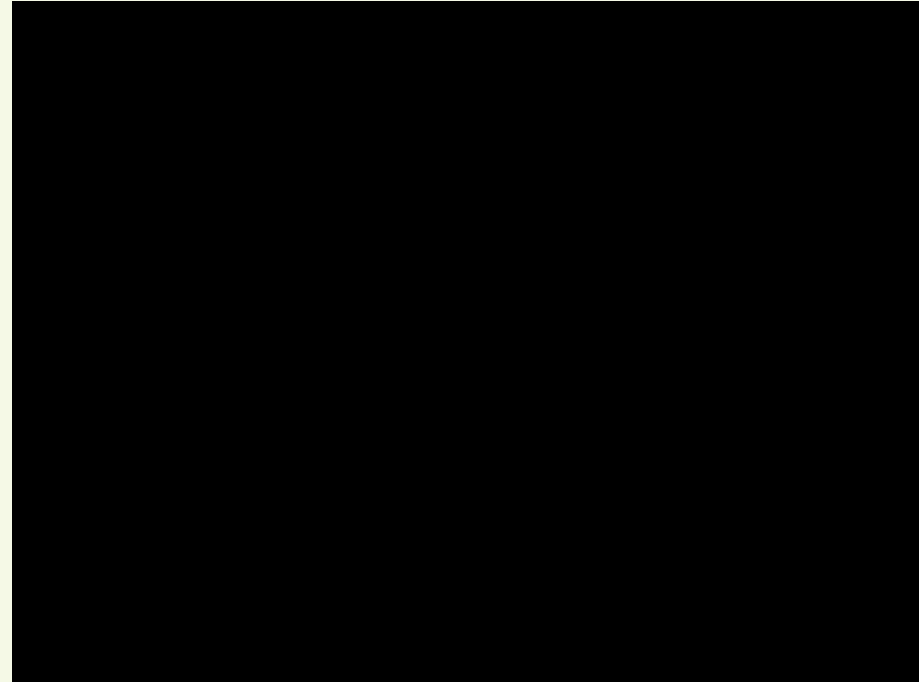
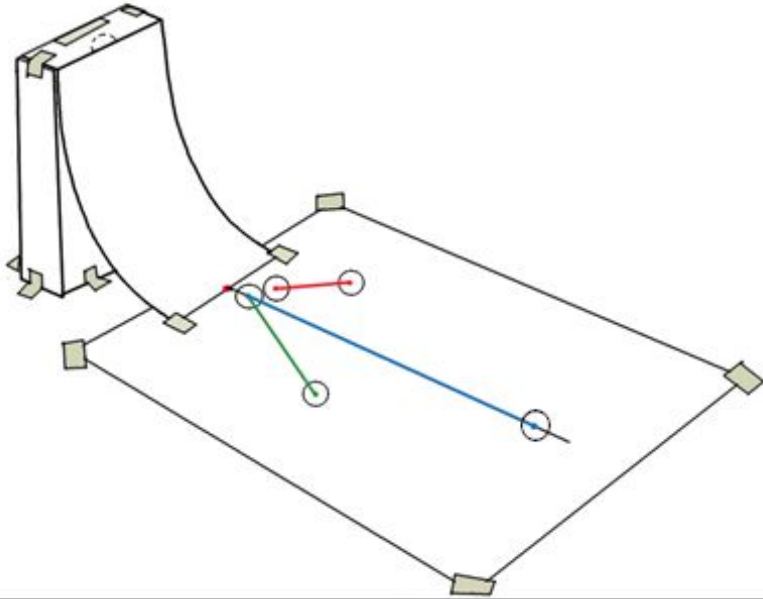
Very versatile apparatus:

1. single student or groups
2. explores of a lot of aspects in collisions
3. students build it and make it effective.
4. can be used to foster creativity.

# Presentation of the activity & Aims

- Discover that in collisions there is a conserved quantity (Linear Momentum) and that the conservation is vectorial in nature
- Introduction to Modern Physics.  
( Particle and Nuclear physics, Special Relativity, Quantum Mechanics )

# Description of the apparatus



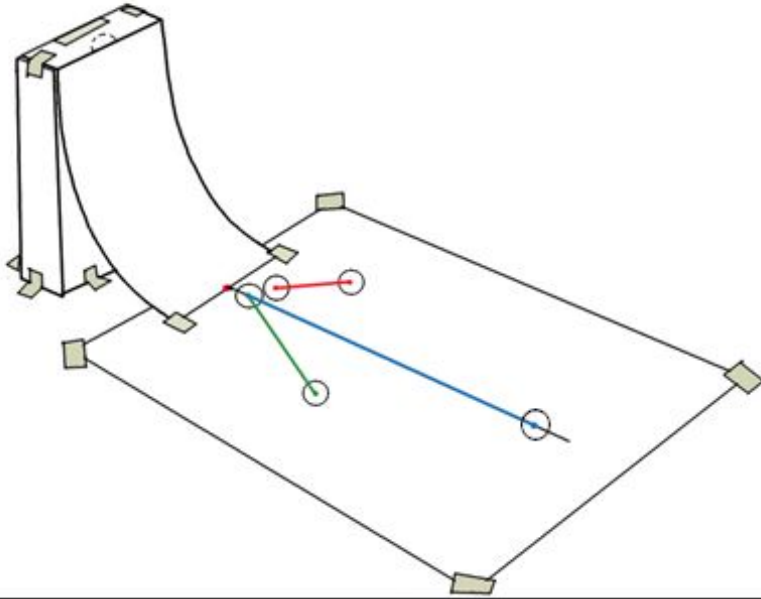
# Description of the apparatus

## The idea

If we measure the lengths of the tracks of the coins we have information about the velocity vectors involved in the collision.

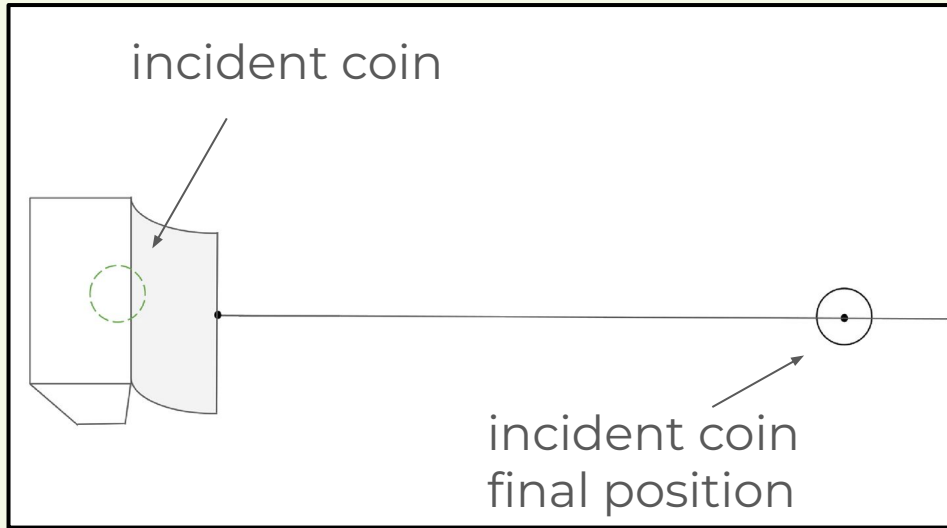
The friction  $F$  acts until the coins come to a stop, so the following relation holds

$$FL = \frac{1}{2}mv^2 \rightarrow v \propto \sqrt{L}$$





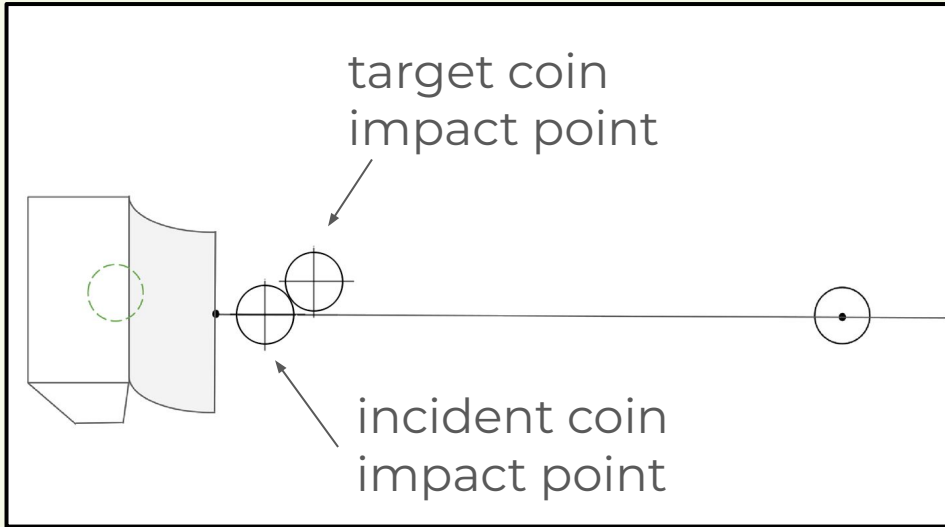
# Description of the apparatus



## Step 1.

Determine the final position of the incident coin if no collision occurs.

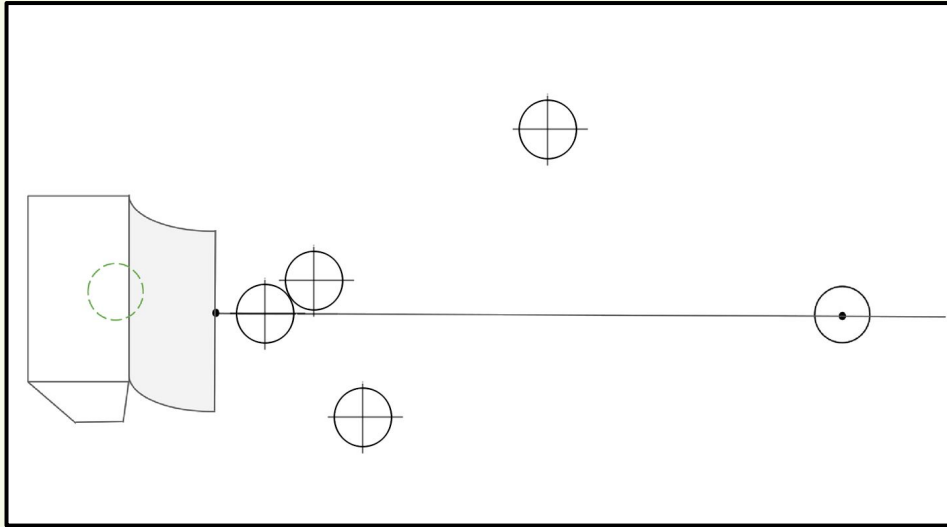
# Description of the apparatus



## Step 2.

Choose the impact (initial) positions of both the coins.

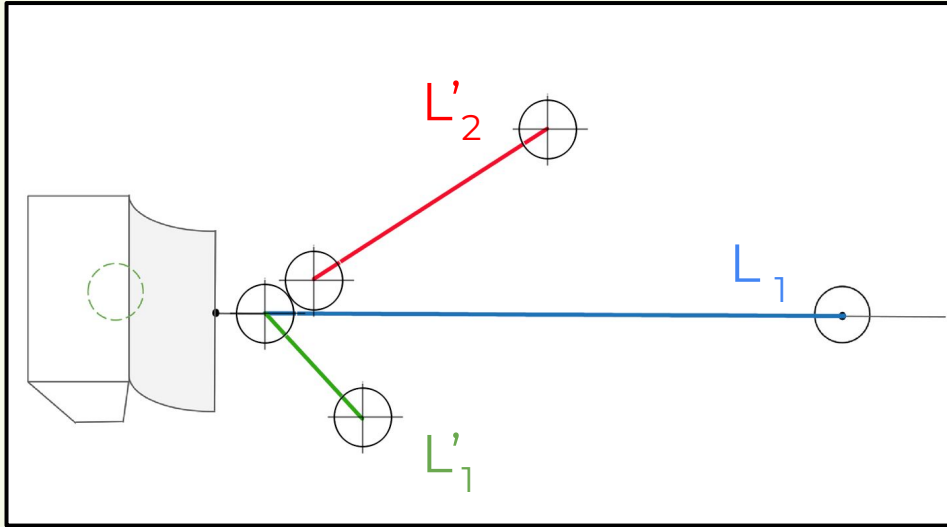
# Description of the apparatus



## Step 3.

Perform the collision and determine the final positions of the coins.

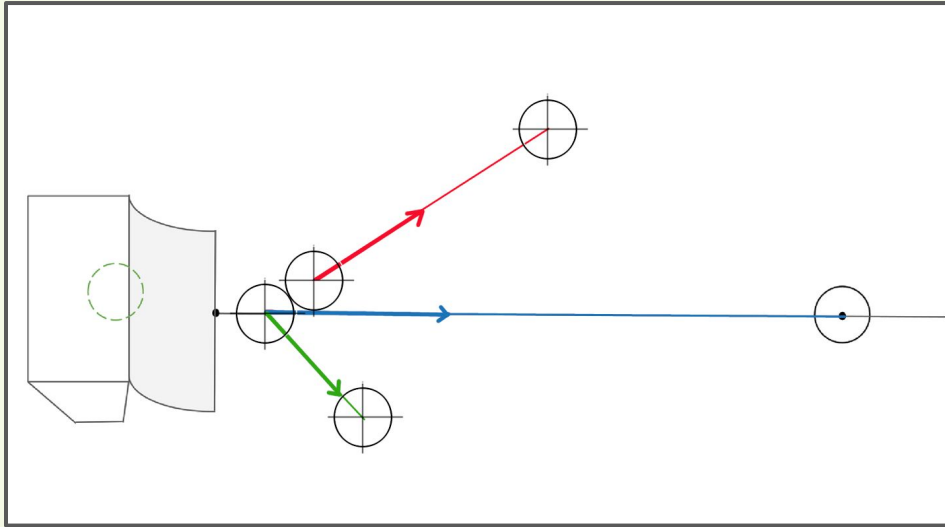
# Description of the apparatus



## Step 4.

Draw the directions of the tracks and measure the lengths.

# Description of the apparatus



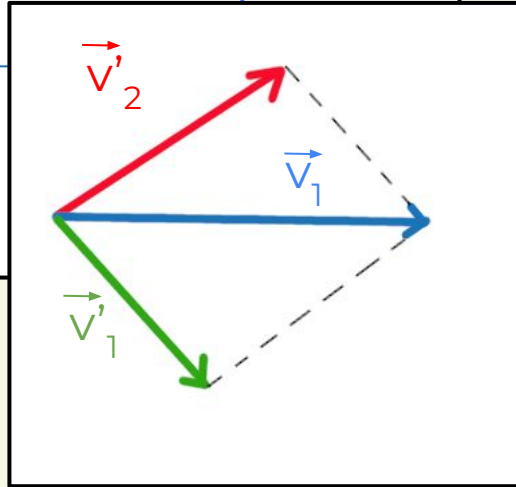
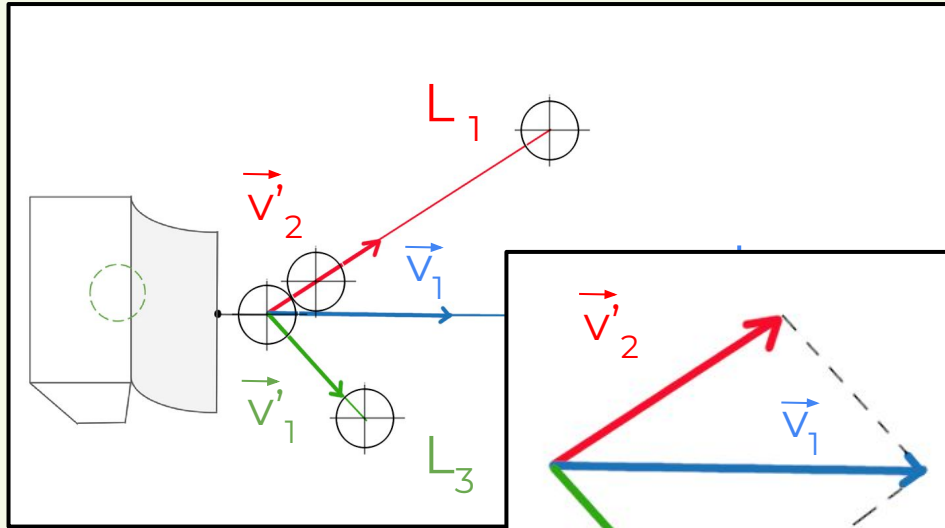
## Step 5.

According to the relation

$$v \propto \sqrt{L}$$

Draw the velocity vectors before and after the collision.

# Description of the apparatus



## Step 6.

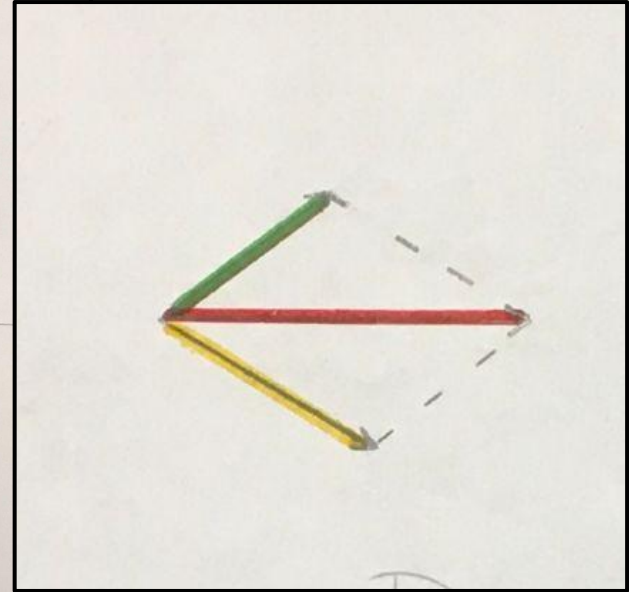
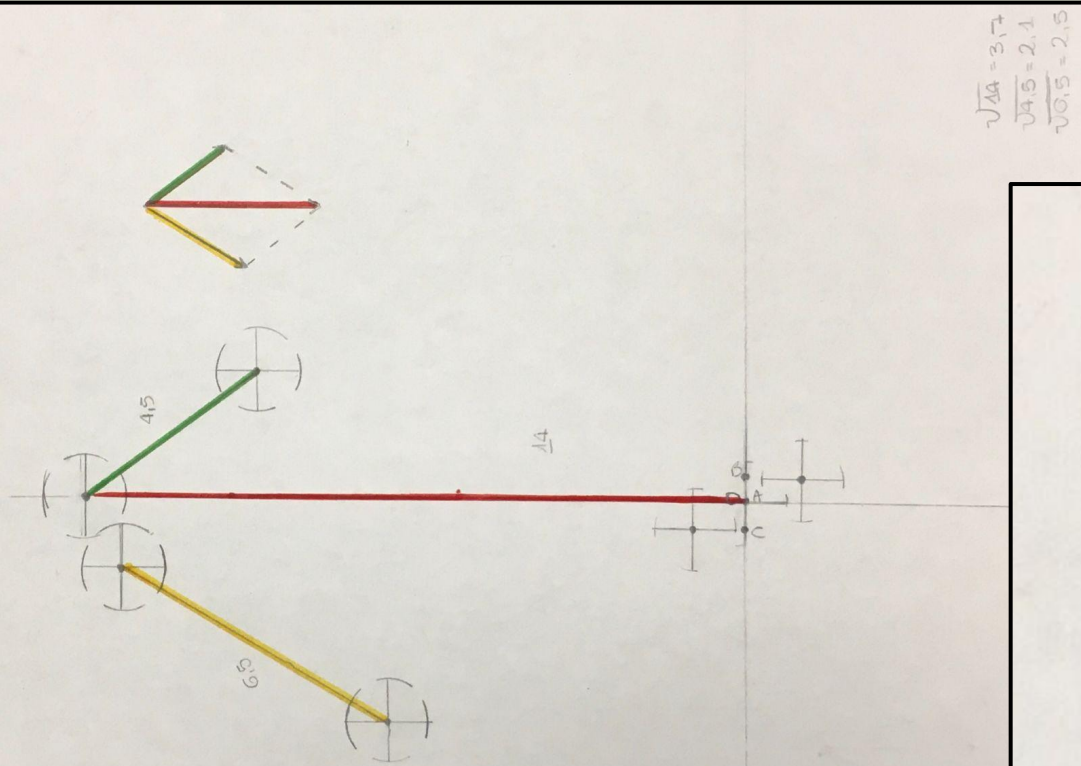
Look if the momentum vector is conserved:

$$m\vec{v}_1 + m\vec{v}_2 = m\vec{v}'_1 + m\vec{v}'_2$$

$$\vec{v}_1 + \vec{v}_2 = \vec{v}'_1 + \vec{v}'_2$$

$$\vec{v}_1 = \vec{v}'_1 + \vec{v}'_2$$

# Results achieved in the classroom

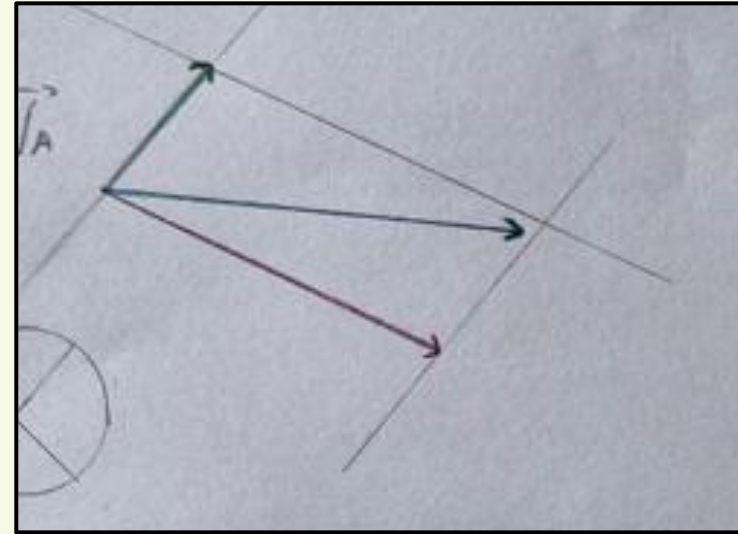


# Results achieved in the classroom

$\vec{p}_i = m_T \vec{V}_T + m_A \vec{V}_A$   
 $\vec{p}_f = m_T \vec{V}_T + m_A \vec{V}_A$   
 $\vec{p}_i = \vec{p}_f$   
 $m_T \vec{V}_T = m_T \vec{V}_T + m_A \vec{V}_A$   
 $\vec{V}_A = \vec{V}_T + \vec{V}_A$

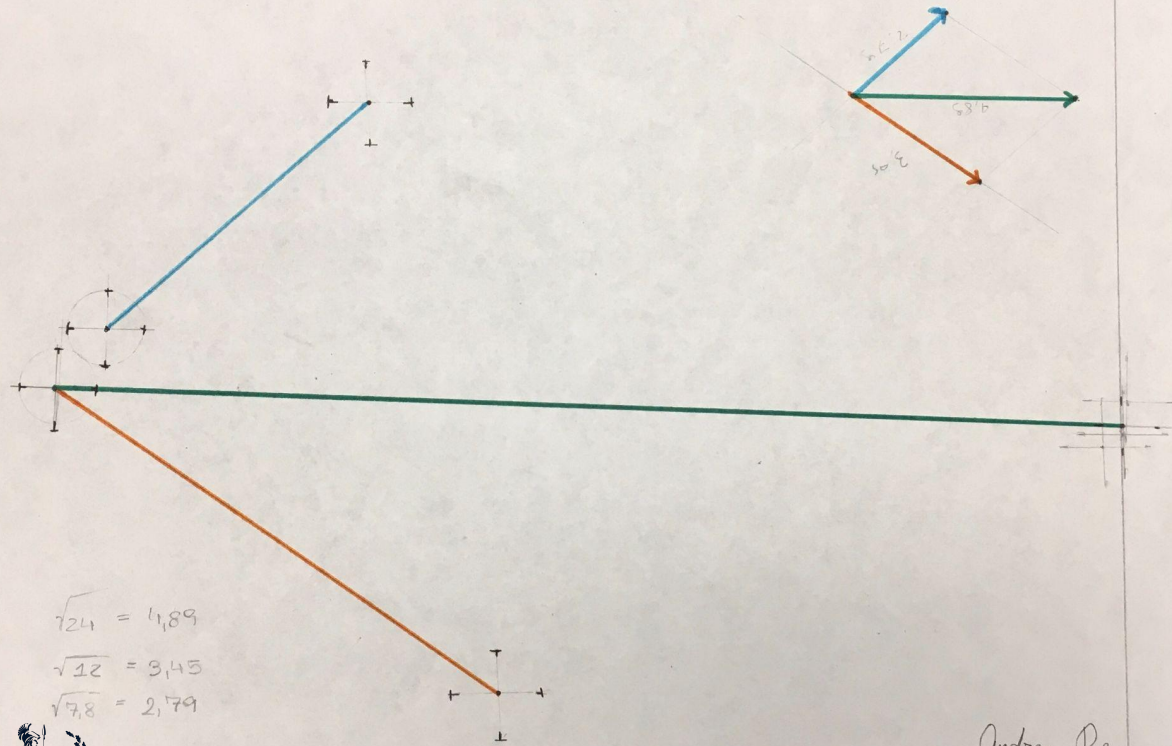
$m_T = m_A = m$   
 $\vec{V}$   
 $F_e L = 0 + \frac{1}{2} m v^2 \rightarrow$  teorema dell'energia cinetica, poiché l'energia potenziale gravitazionale  
 $2 F_e L = m v^2$   
 $v = \sqrt{\frac{2 F_e L}{m}} \cdot \sqrt{L}$

è proporzionale perché le monete sono uguali, per cui basta misurare la radice di  $L$ .





# Results achieved in the classroom

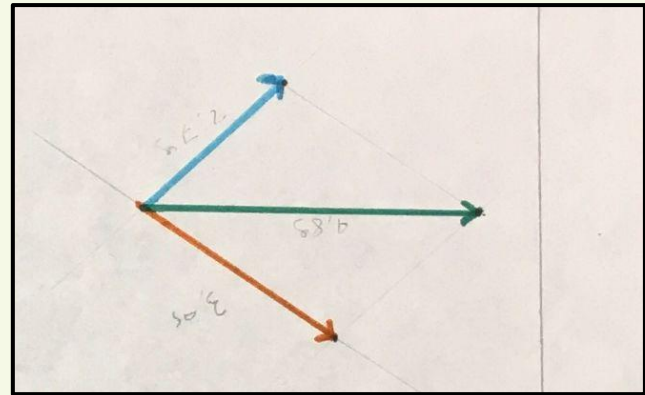


$$\sqrt{24} = 4,89$$
$$\sqrt{12} = 3,45$$
$$\sqrt{7,8} = 2,79$$

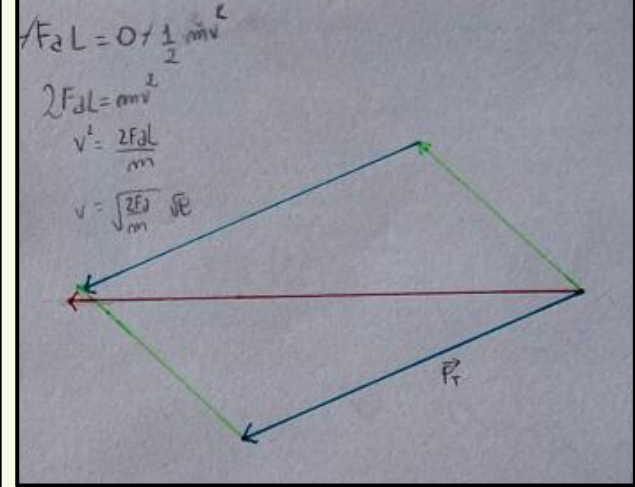
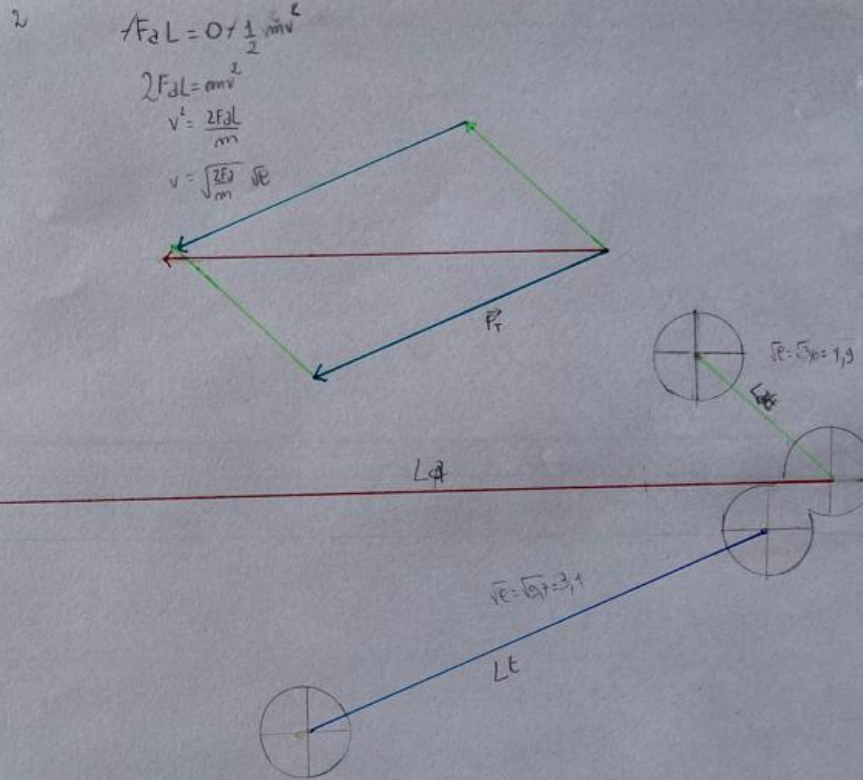


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Andrea Re  
Alessandro D'agali  
Riccardo Lanella



# Results achieved in the classroom



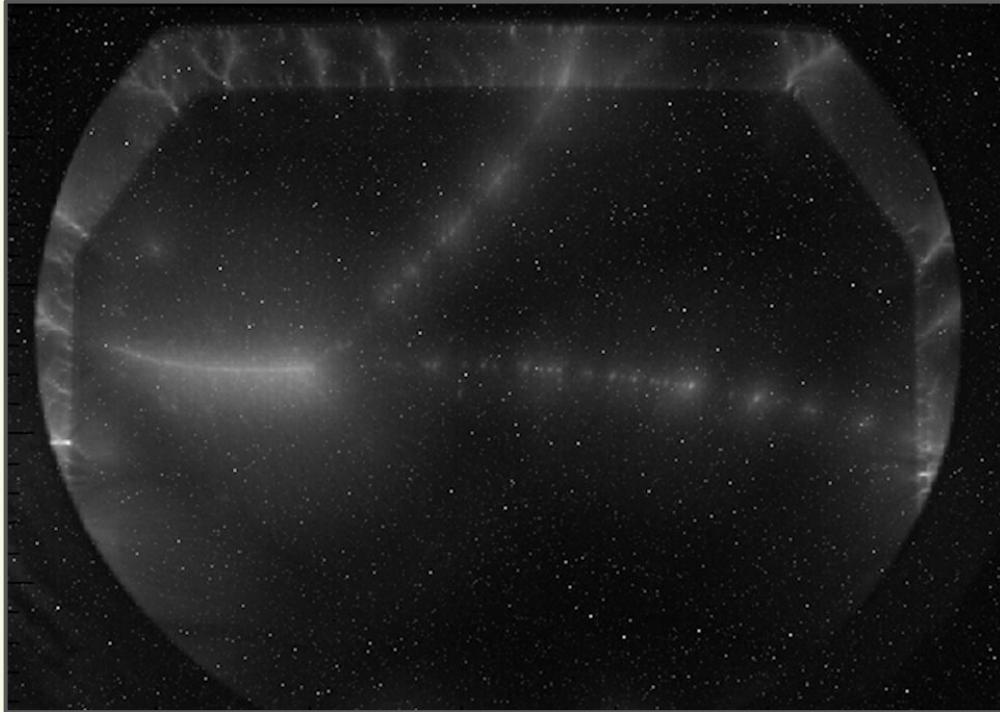
# Results achieved in the classroom



# Results achieved in the classroom



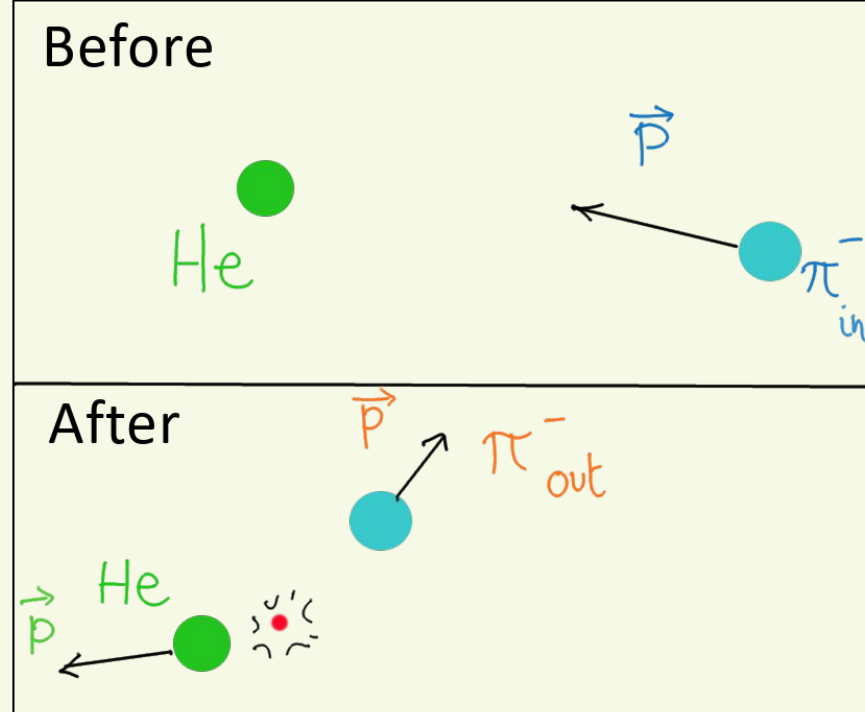
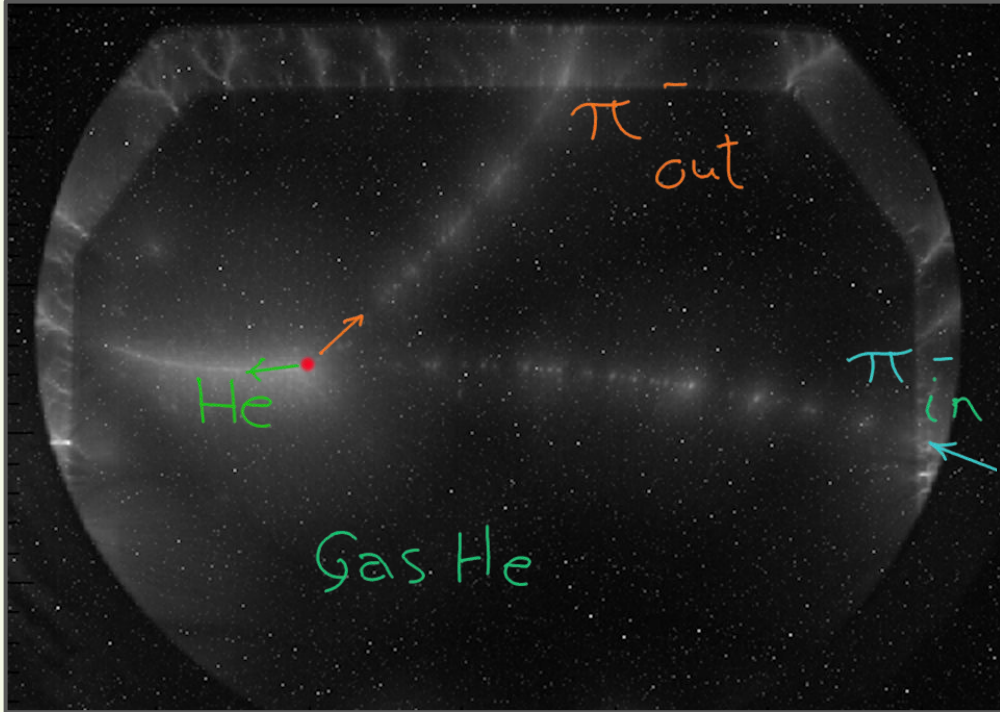
# From the experiment to modern physics



This is a collision event in particle physics experiment.

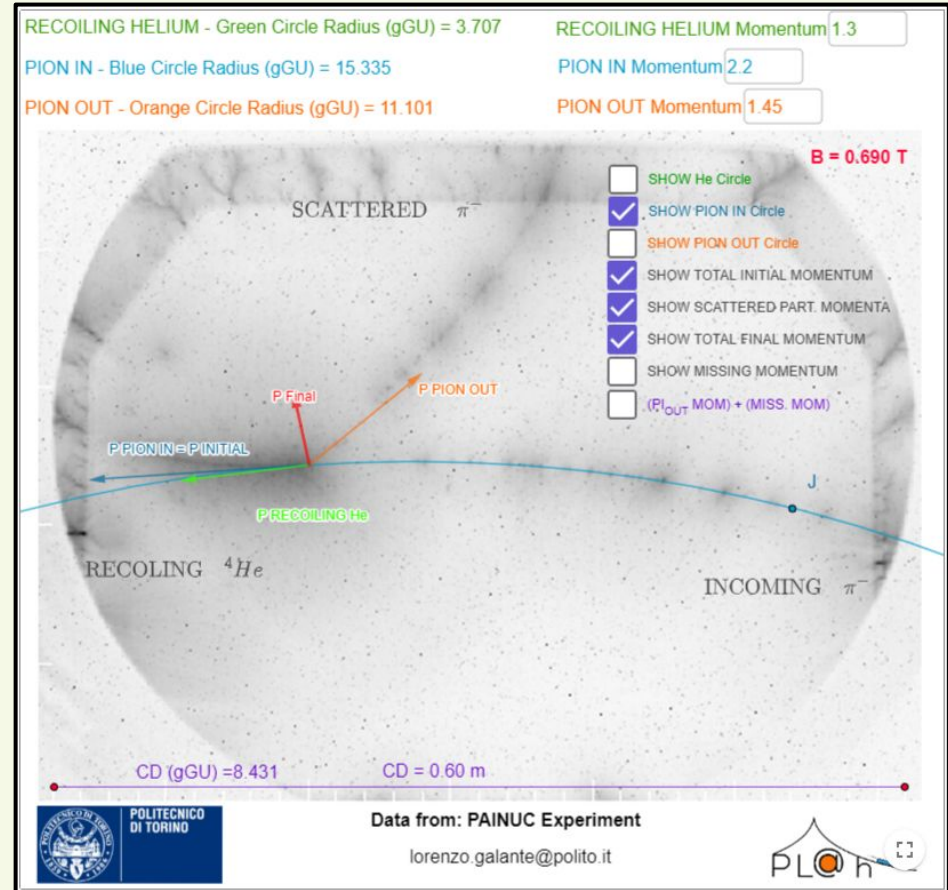
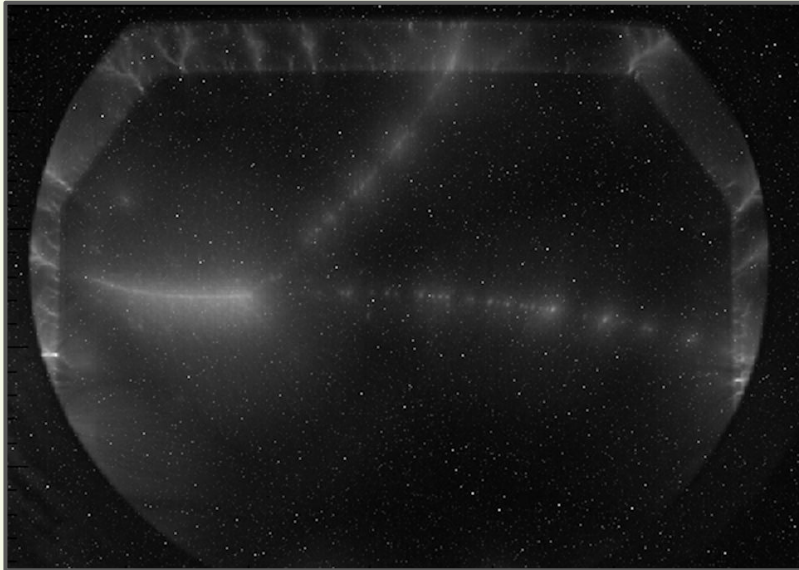
The situation is exactly the same as the one we had in the coins collision experiment!

# From the experiment to modern physics



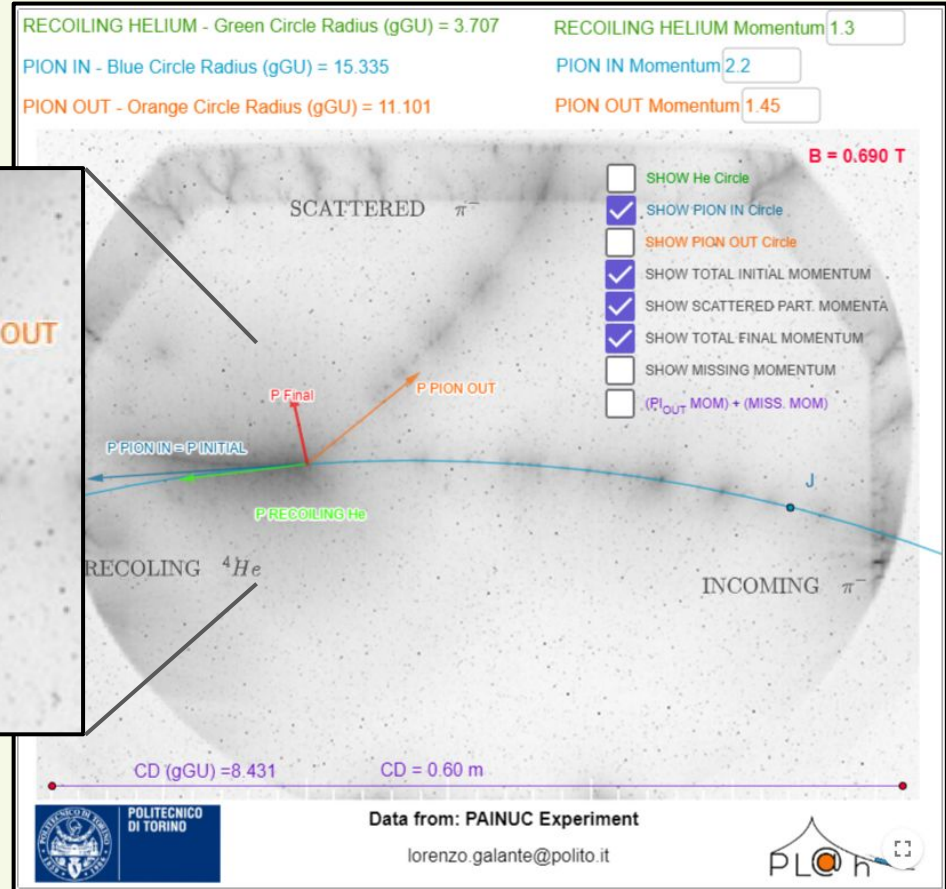
# From the experiment to modern physics

## Conservation laws as a tool for discovery in nuclear physics



# From the experiment to modern physics

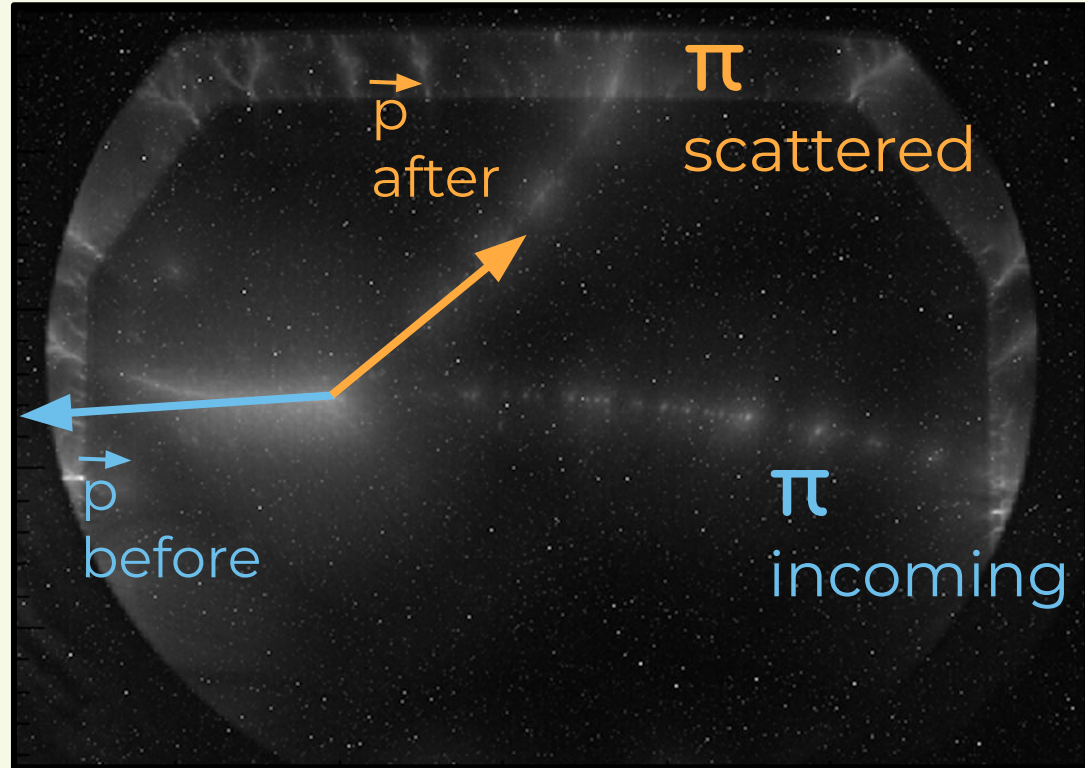
## Conservation laws as a tool for discovery in nuclear physics



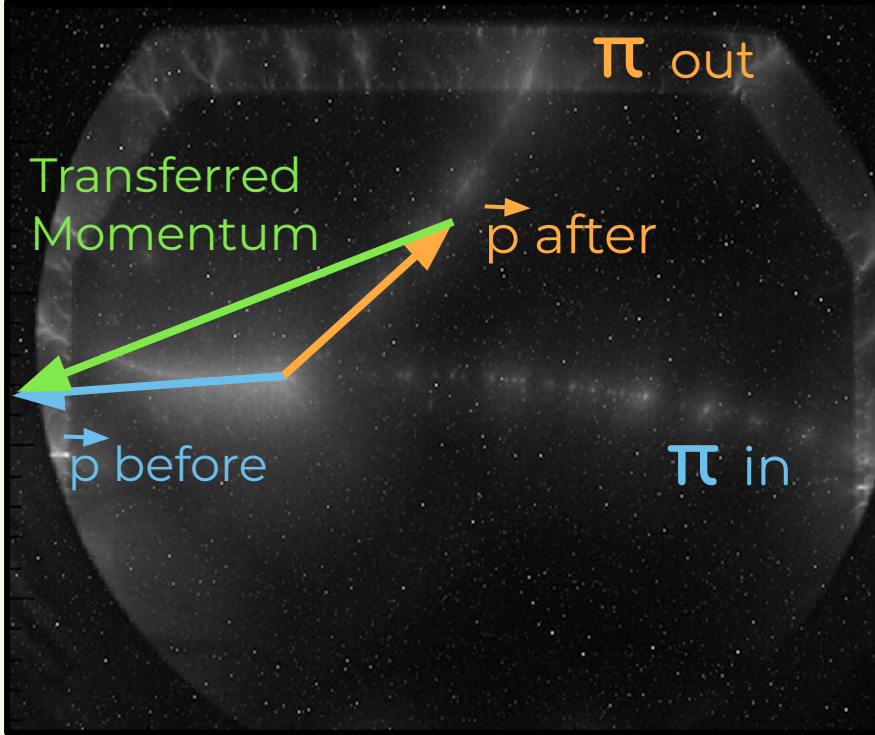
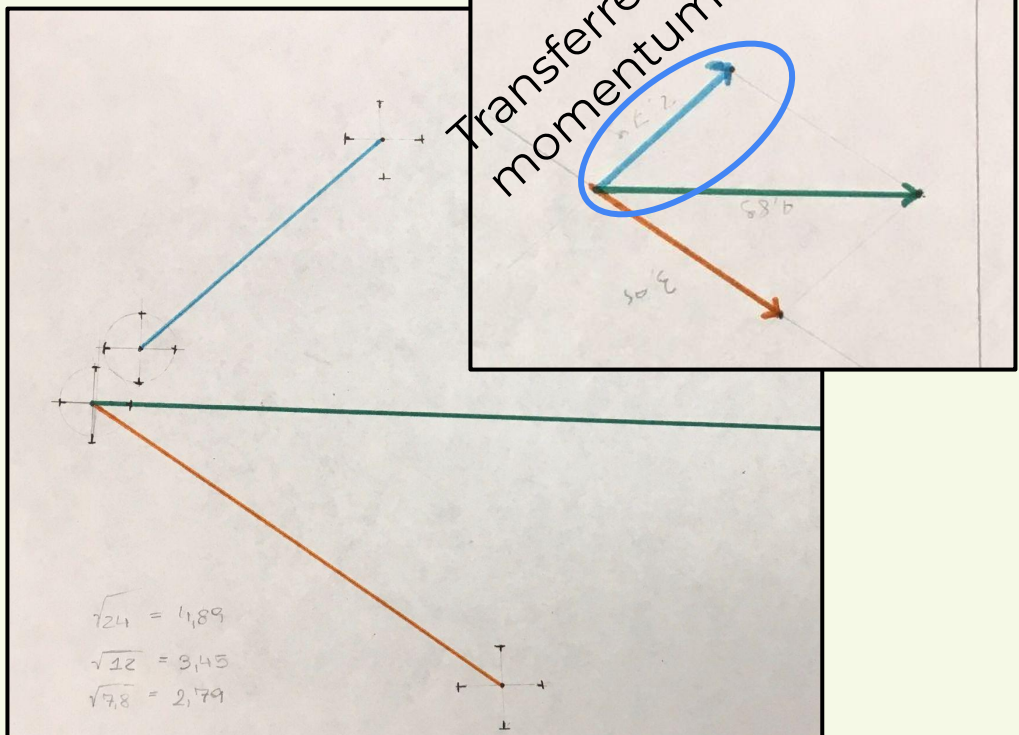


# From the experiment to modern physics

## Transferred Momentum



# The same occurs in the coin collision ...

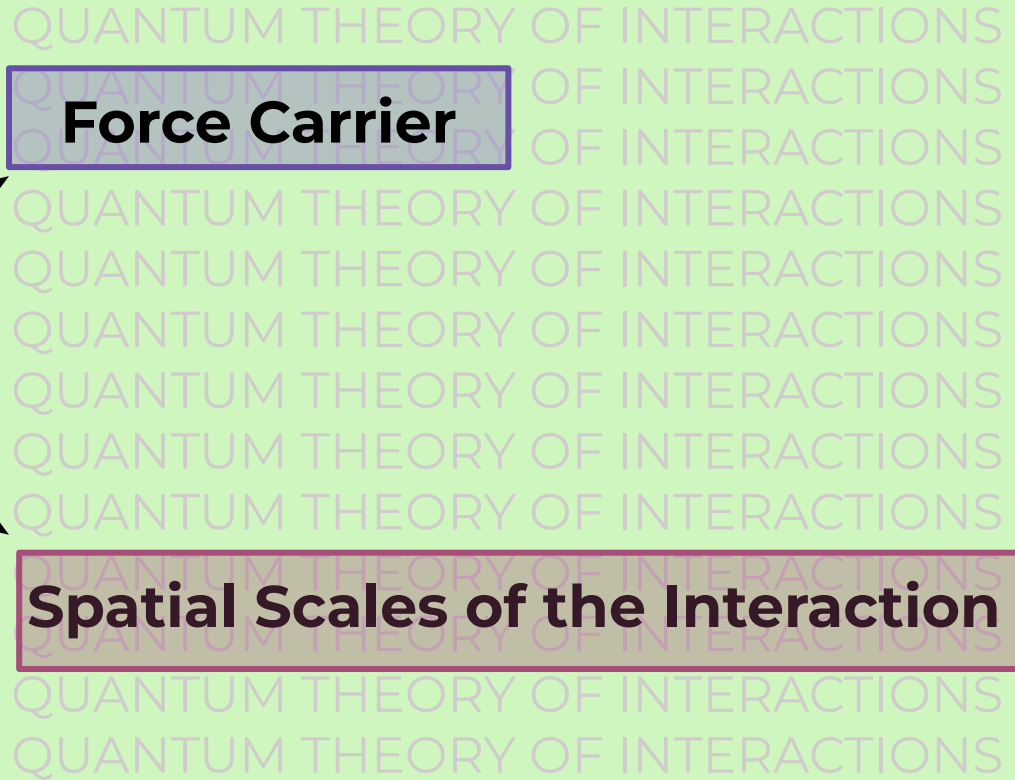


# From the experiment to modern physics

**Transferred Momentum**

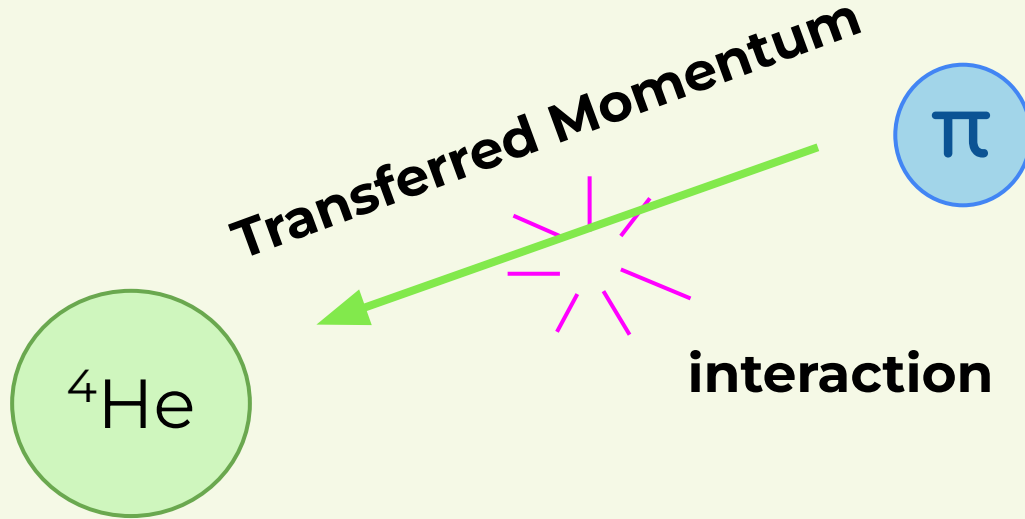
**Force Carrier**

**Spatial Scales of the Interaction**



# From the experiment to modern physics

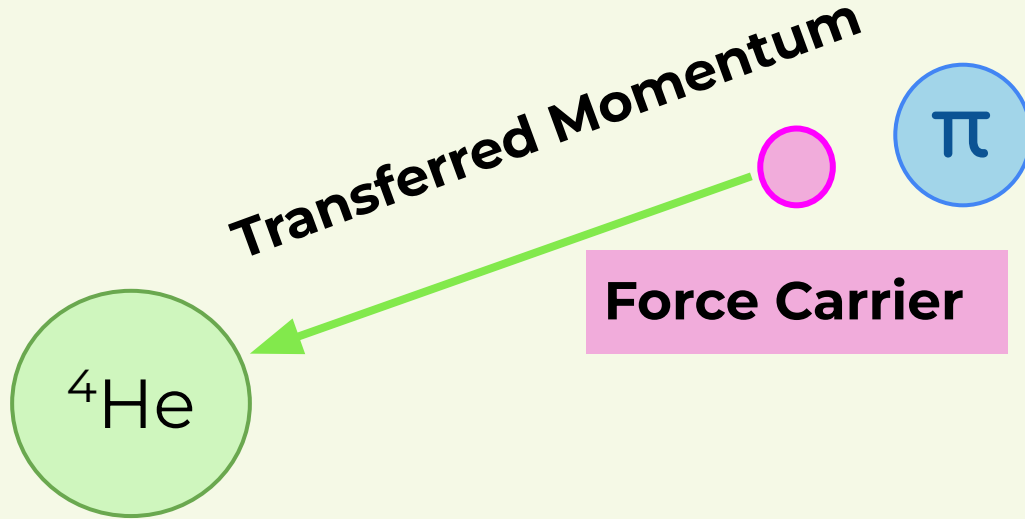
## Force Carrier



... What carries this momentum?

# From the experiment to modern physics

Force Carrier



Force Carrier

A "particle". The force carrier !

# From the experiment to modern physics

## Spatial Scales of interaction

Heisenberg Relation for  
the quantum system

Force Carrier:

$$\Delta p \cdot \Delta x \sim \hbar/2$$

We assume:  $\Delta p \sim p$

Therefore  $\Delta x \sim \frac{\hbar}{2p}$

# From the experiment to modern physics

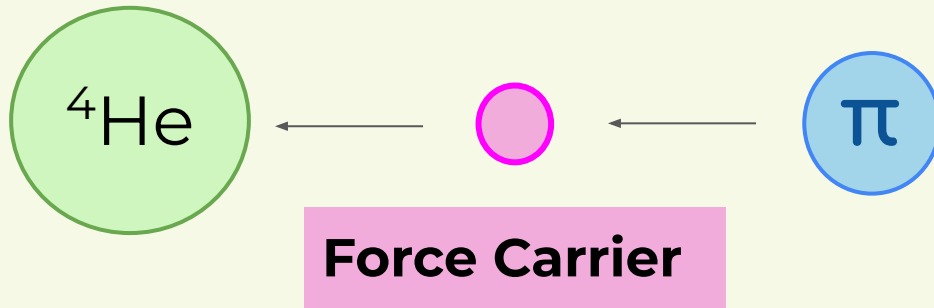
**Spatial Scales of interaction**

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

$\Delta x$  is the Dispersion in Space of the Force Carrier (FC).

It tells us about “how big” the FC is.

Therefore, it tells at what scales the interaction occurs





Physics

# Geometrical Optics



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# Let's shed some light on coffee!





Physics

# Quantum Mechanics



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# Quantum mechanics with a straw

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This point naturally leads us to think that the electron will certainly escape one (or) electrons with constant speed would certainly escape (or) electrons, taking in mind that an accelerated charge emits electromagnetic radiation, thus losing part of its energy, we come to the conclusion that this kind of interpretation leaves some open questions. Just to make an example, the Hydrogen atom is the typical quantum system affected by this problematic situation.

According to the Copenhagen interpretation, an electron in an infinite potential well should accelerate, hence losing part of its energy by electromagnetic radiation. This fact conflicts with the idea of stationary states, i.e. states with well defined and constant energy.

The overall picture  
Let us draw a picture of what we have learned up to now.

Hydrogen emission spectrum

$$\hbar \frac{\partial \Psi}{\partial t} = -\frac{\hbar^2}{2m} \frac{\partial^2 \Psi}{\partial x^2} + V\Psi$$

$$|\Psi|^2 = \frac{dP}{dx} \Rightarrow P(x)_{x_1, x_2} = \int_{x_1}^{x_2} |\Psi|^2 dx$$

BOUND STATE PROBLEM

1. Our starting point was the Schrödinger equation whose great achievement was the explanation of the Hydrogen discrete spectrum [arrow n.1].

The discussion about the meaning of the  $\Psi(x,t)$  led to the automatic interpretation of a function whose square modulus represents the probability density distribution to find a system

# Quantum mechanics with a straw



## Theoretical model

$$L = 0.208 \text{ m}$$

$$C = 340 \text{ m/s}$$

$$f_1 = c / (2L) = \mathbf{817 \text{ Hz}};$$

$$f_2 = 2 f_0; \quad f_3 = 3 f_0 \quad \dots$$

# Quantum mechanics with a straw



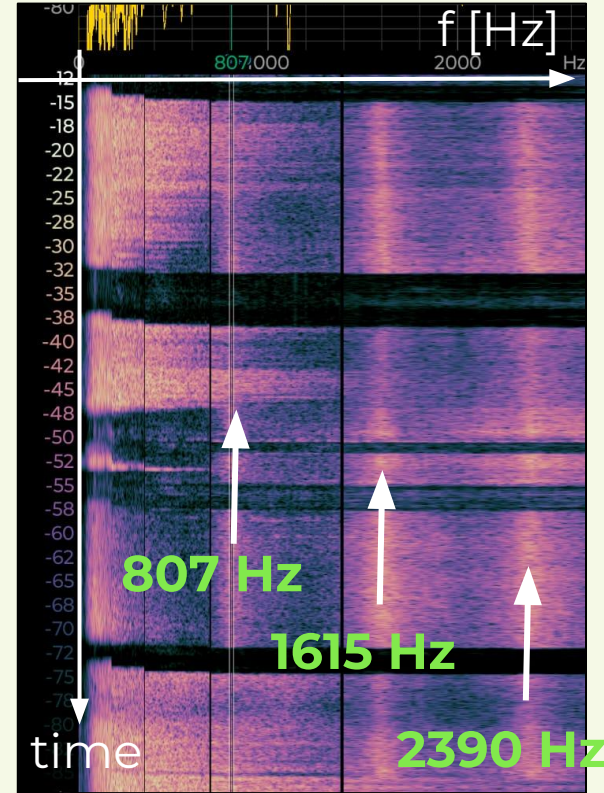
$$L = 0.208 \text{ m}$$

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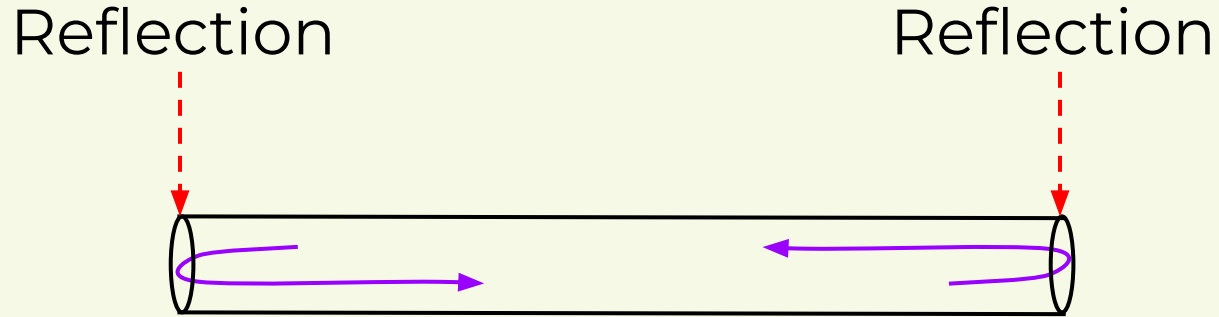
$$f_1 = c / (2L) = \mathbf{817 \text{ Hz}}$$

$$f_2 = 2 f_0; \quad f_3 = 3 f_0 \quad \dots$$

## Measurements

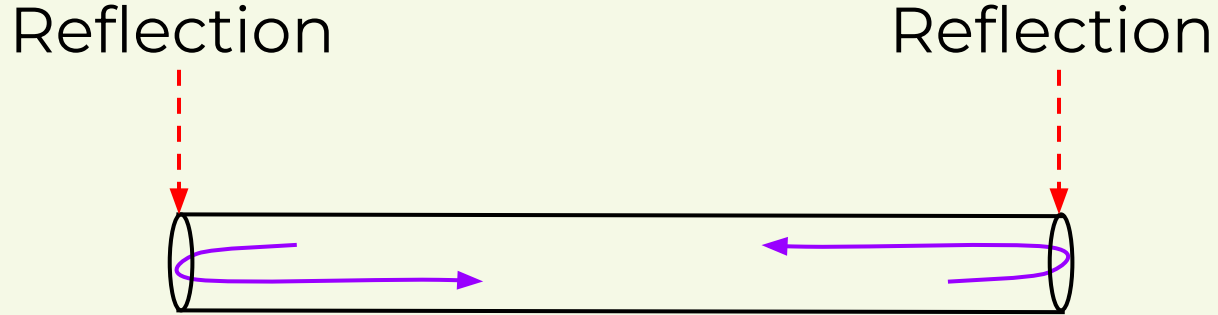


# What's happening in the straw?

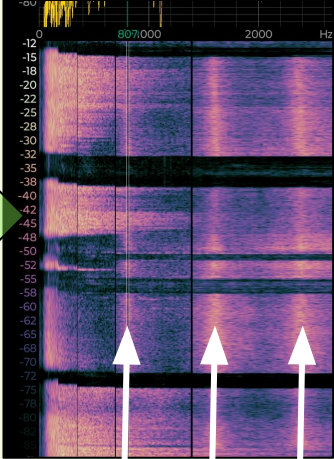
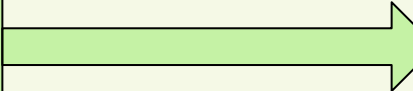


**Wave confined in  
Space!**

# What's happening in the straw?



**Wave confined in Space**



**Quantization!**

# What's happens in the atom?

The same thing



# What's happens in the atom?

The same thing

1.

The **Schroedinger** equation tells us quantum systems are described by a **wave function**

2.

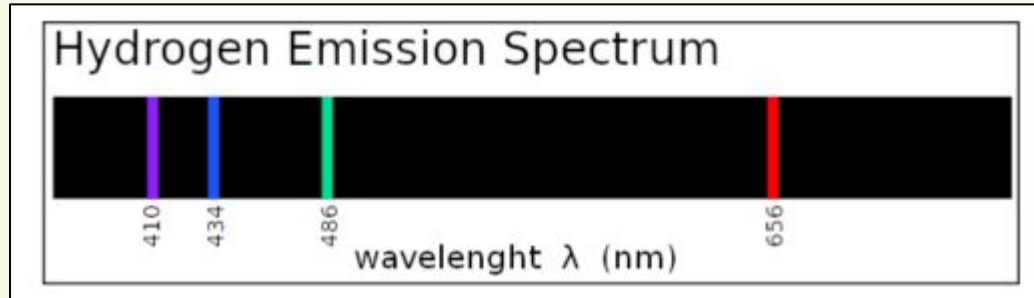
An atom is a quantum systems **confined in space**

3.

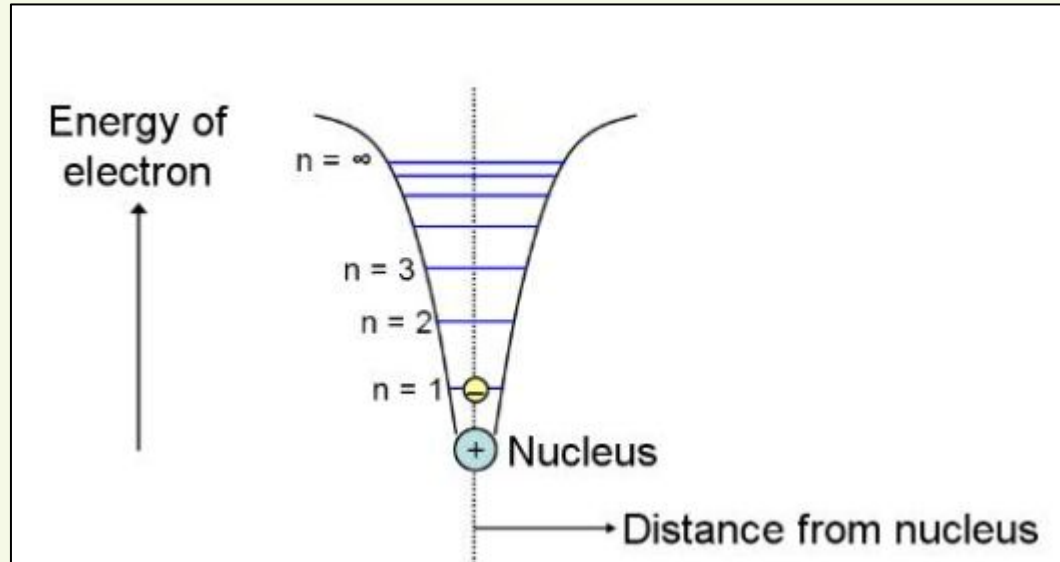
**Waves**  
+  
**confined in space**  
=  
**quantization**

# What's happens in the atom?

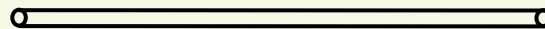
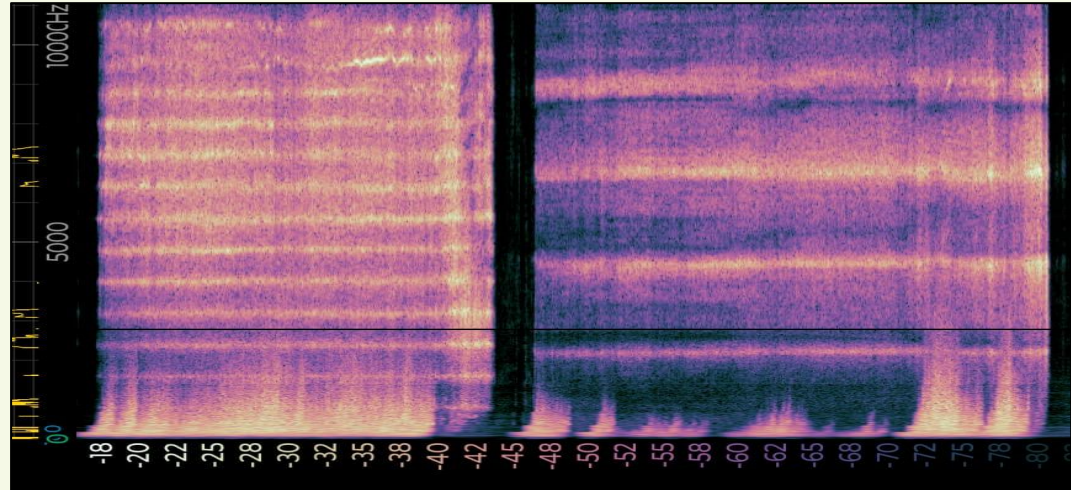
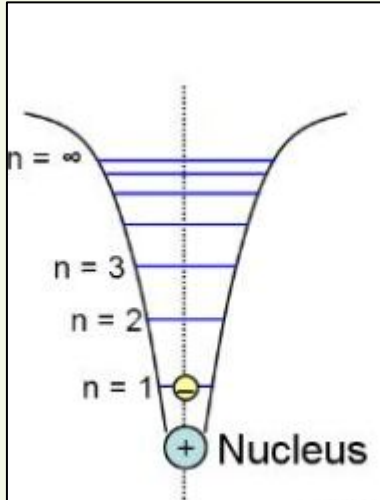
Quantization of  
the Energy levels



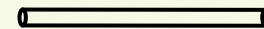
# The straw also explains the decreases of the spacing of the energy levels



# The straw also explains the decreases of the spacing of the energy levels



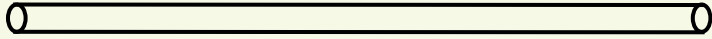
$L = 20$  cm



$L = 7$  cm

# The analogy stands on the equations

Straw



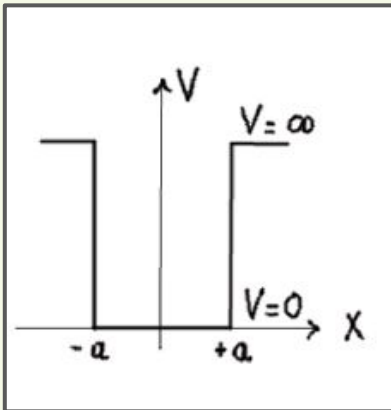
D'Alembert wave equation

$$\frac{\partial^2 y}{\partial x^2} - \frac{1}{c^2} \frac{\partial^2 y}{\partial t^2} = 0$$

that for harmonic solutions becomes ...

$$\frac{\partial^2 y}{\partial x^2} = -k^2 y$$

## Quantum system in an infinite potential well



Schroedinger stationary wave equation

$$-\frac{\hbar^2}{2m} \frac{\partial^2 \Psi}{\partial x^2} = E \Psi$$

That may be rewritten ...

$$\frac{\partial^2 \Psi}{\partial x^2} = -k^2 \Psi$$

# Quantum mechanics with a straw

$$i\hbar \frac{\partial \Psi}{\partial t} = -\frac{\hbar^2}{2m} \frac{\partial^2 \Psi}{\partial x^2} + V\Psi$$