

Title: Quantum Mechanics 14 - The Physics of Electron Spin

Date: Aug 01, 2008 02:00 PM

URL: <http://pirsa.org/08080089>

Abstract: An experimental introduction to electron spin. <br> Learning Outcomes: <br>

â€¢ To develop the classical understanding of a spinning bar magnet, and how we would expect it to be affected on passing through a Stern-Gerlach apparatus. <br>

â€¢ How actual experiments with silver atoms (containing an electron that acts like a tiny spinning bar magnet) give results that are completely different from the above classical expectations. <br>

â€¢ How a variety of different experiments lead to two main conclusions: (1) the spin of an electron is quantized (â€œspin upâ€• or â€œspin downâ€•), and (2) probability plays a fundamental role in the spin direction selected by the Stern-Gerlach apparatus.



# The Physics of Spin

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Otto Stern

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Otto Stern



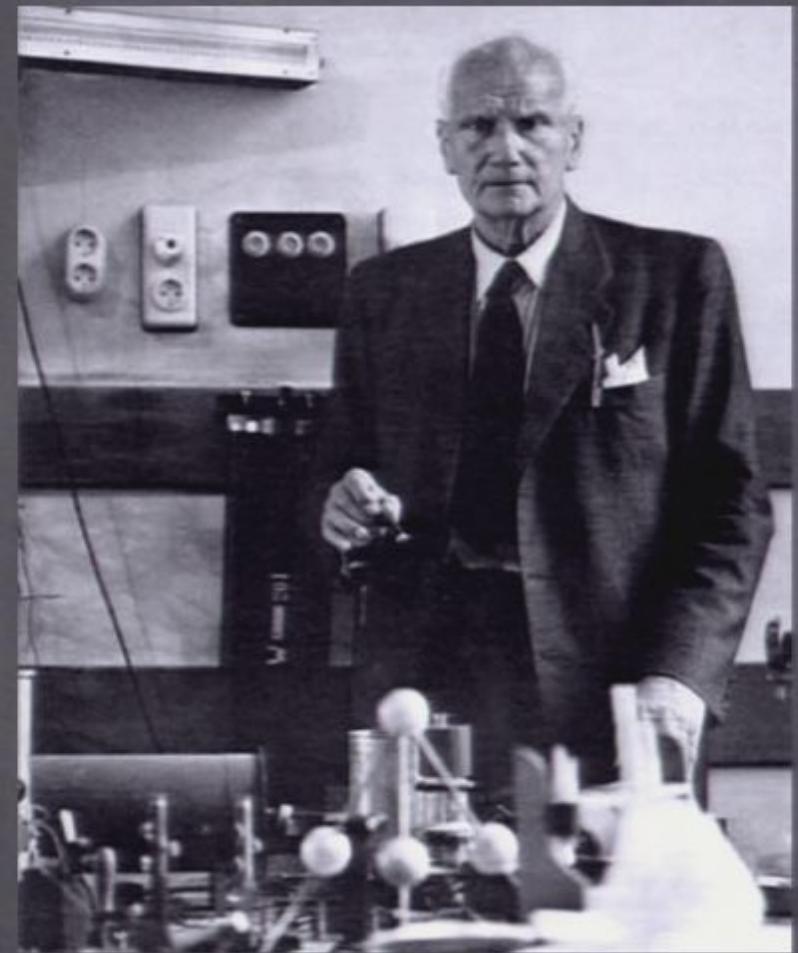
Walther Gerlach

# The Physics of Spin

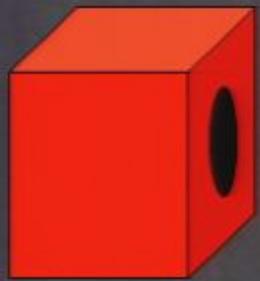


Otto Stern

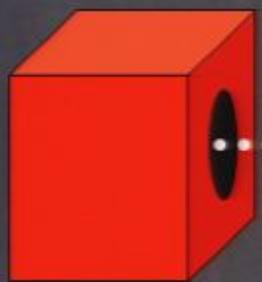
1922: Wrong theory  
→ right experiment



Walther Gerlach

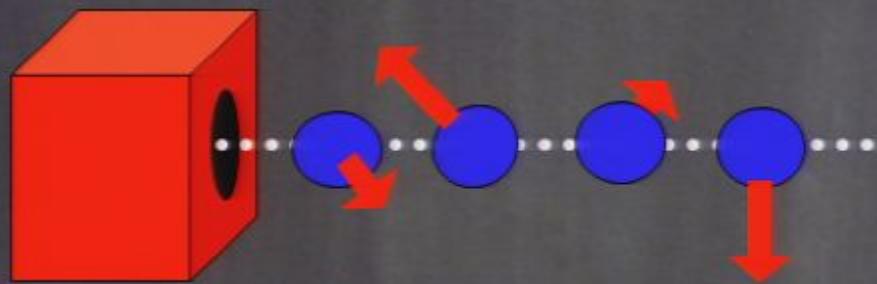


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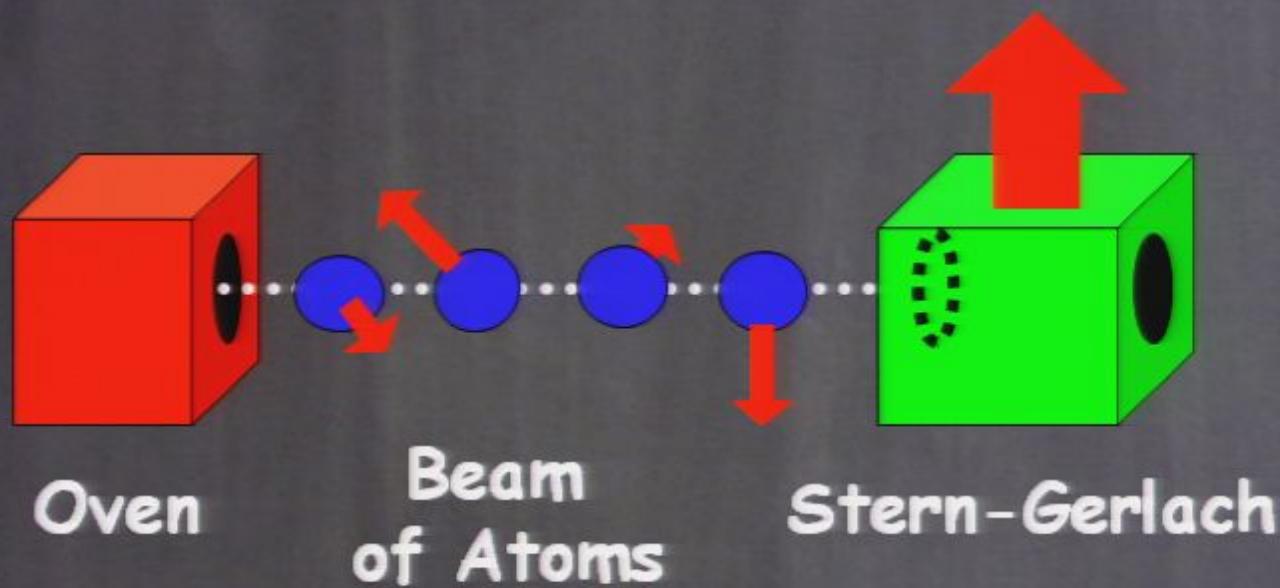


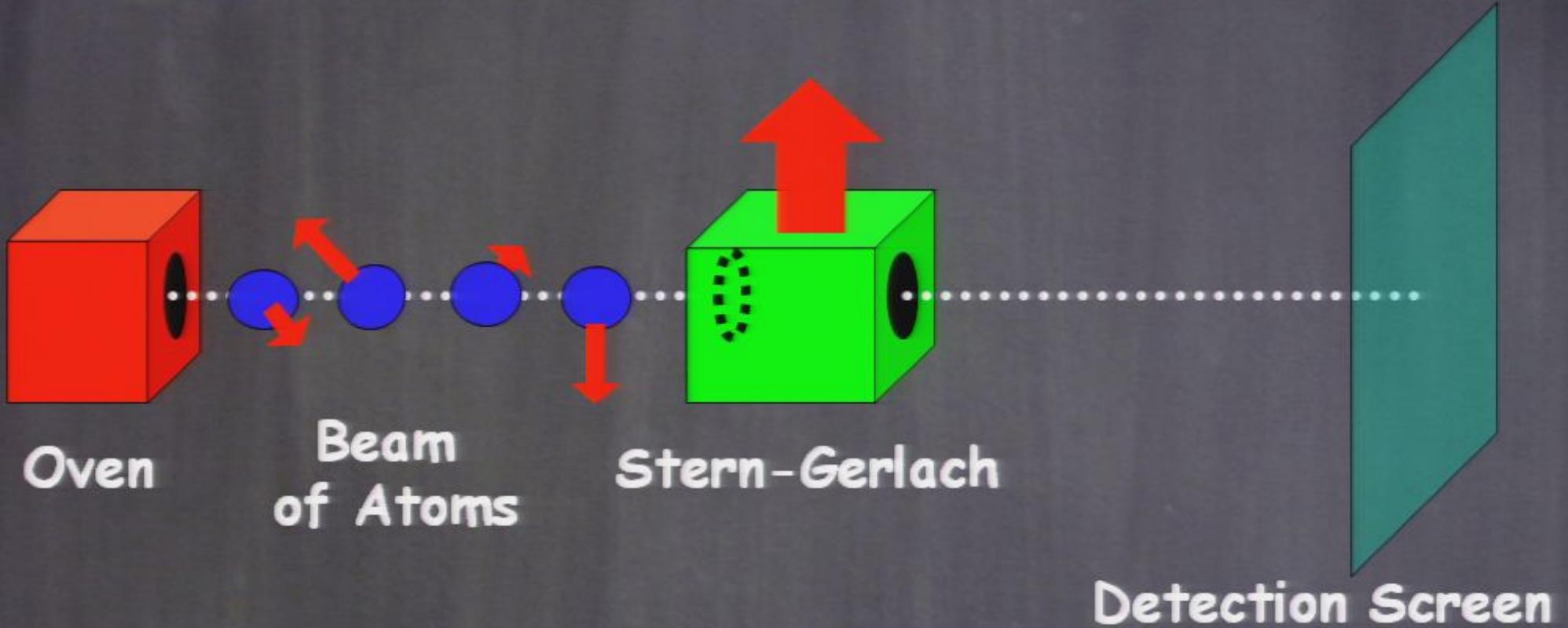
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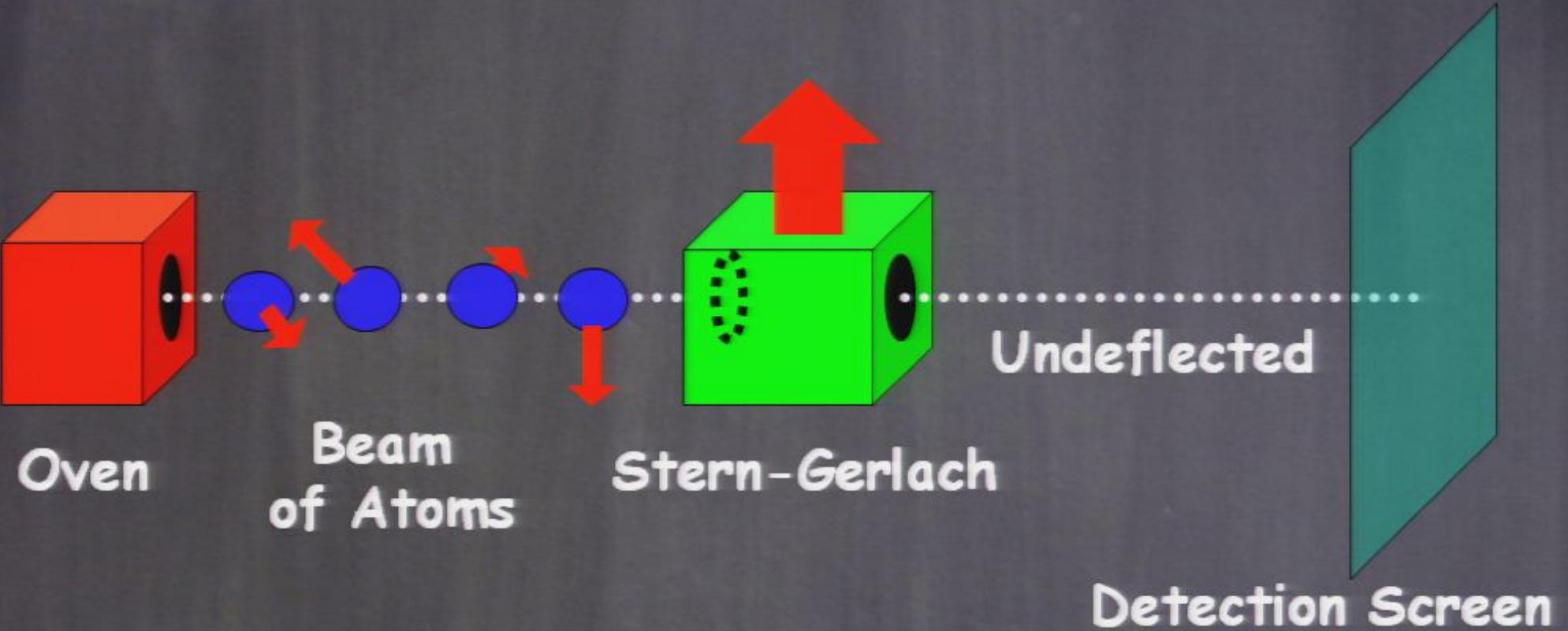
Beam  
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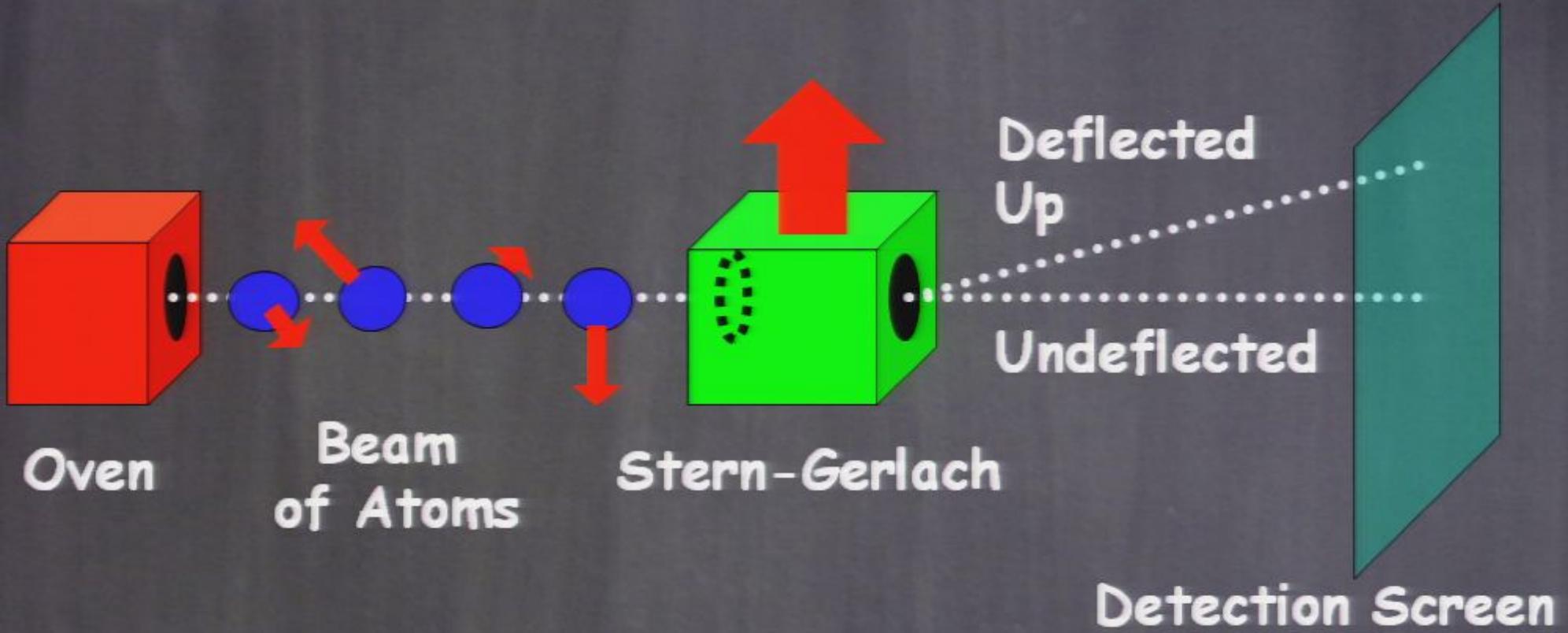


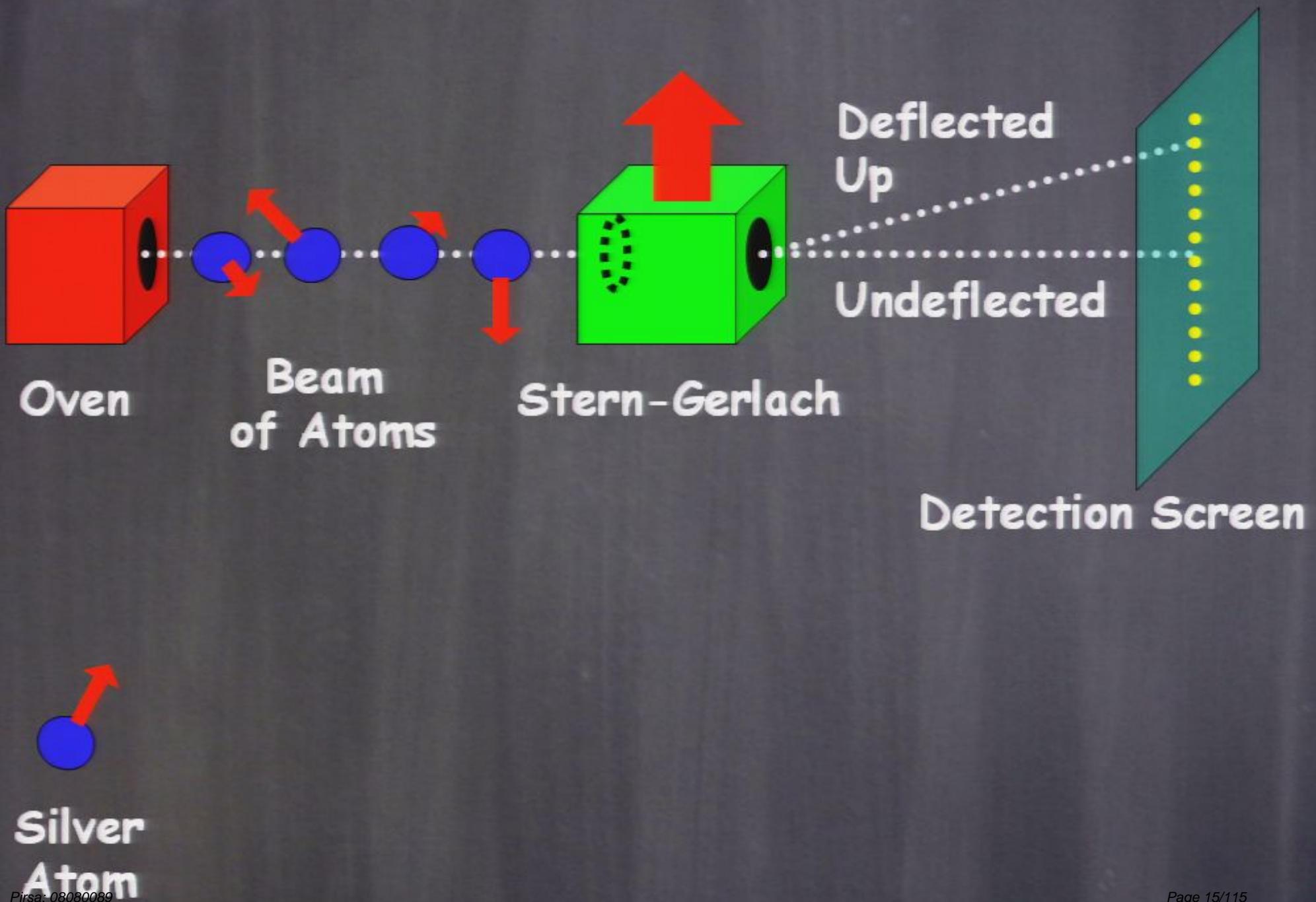
Oven      Beam  
of Atoms

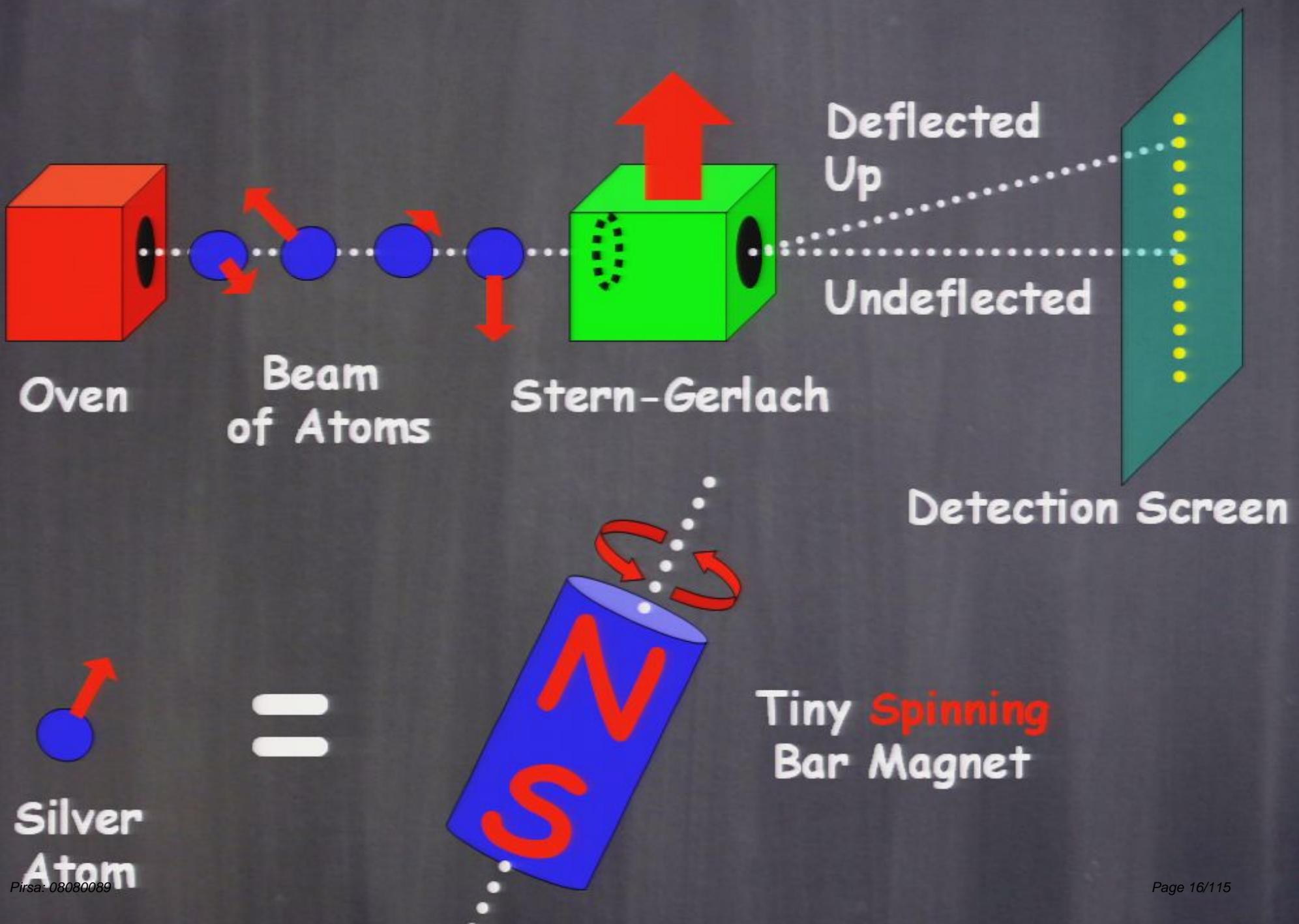


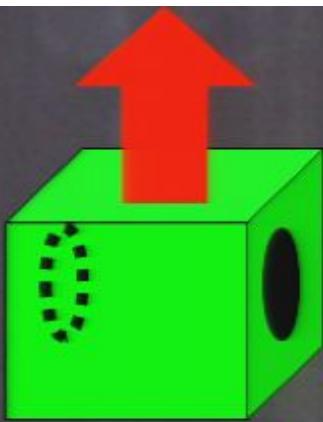


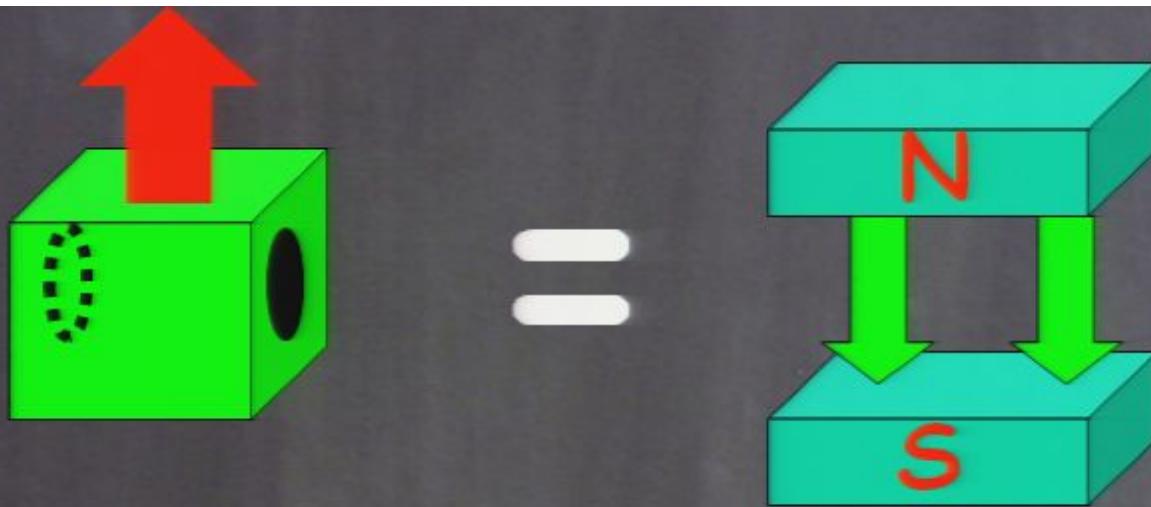


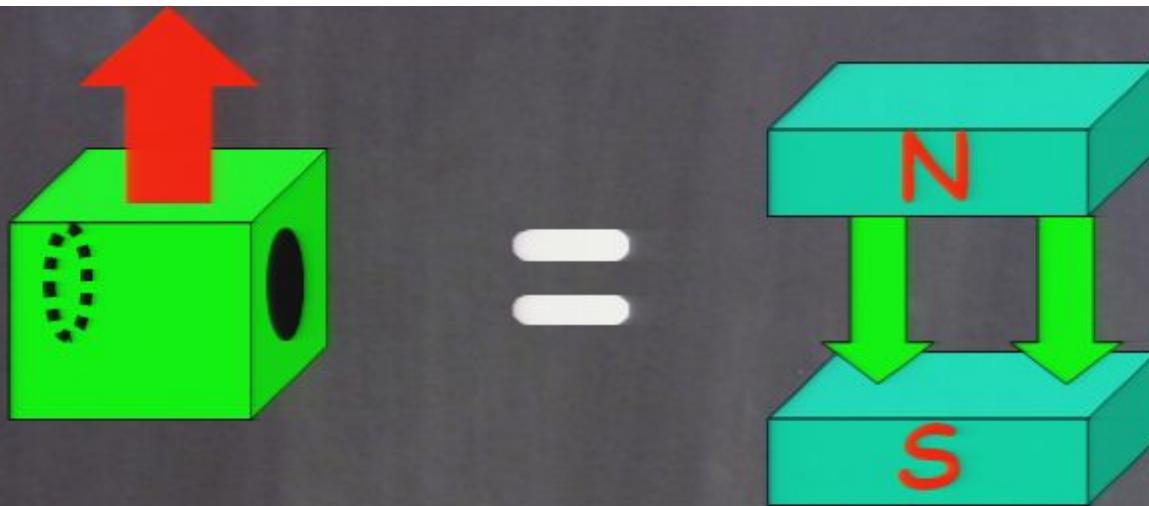




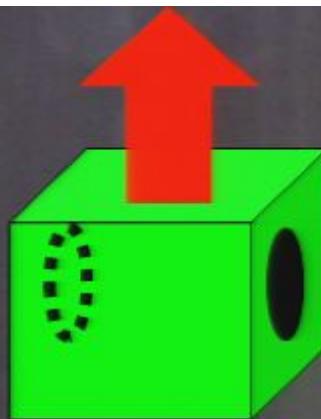




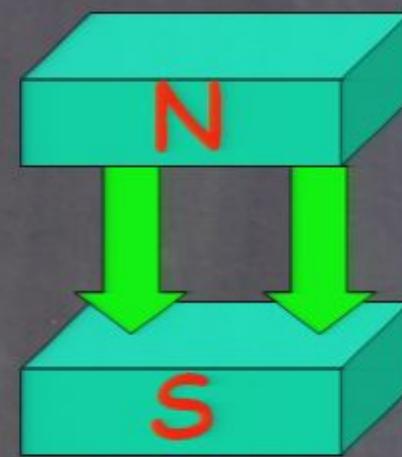




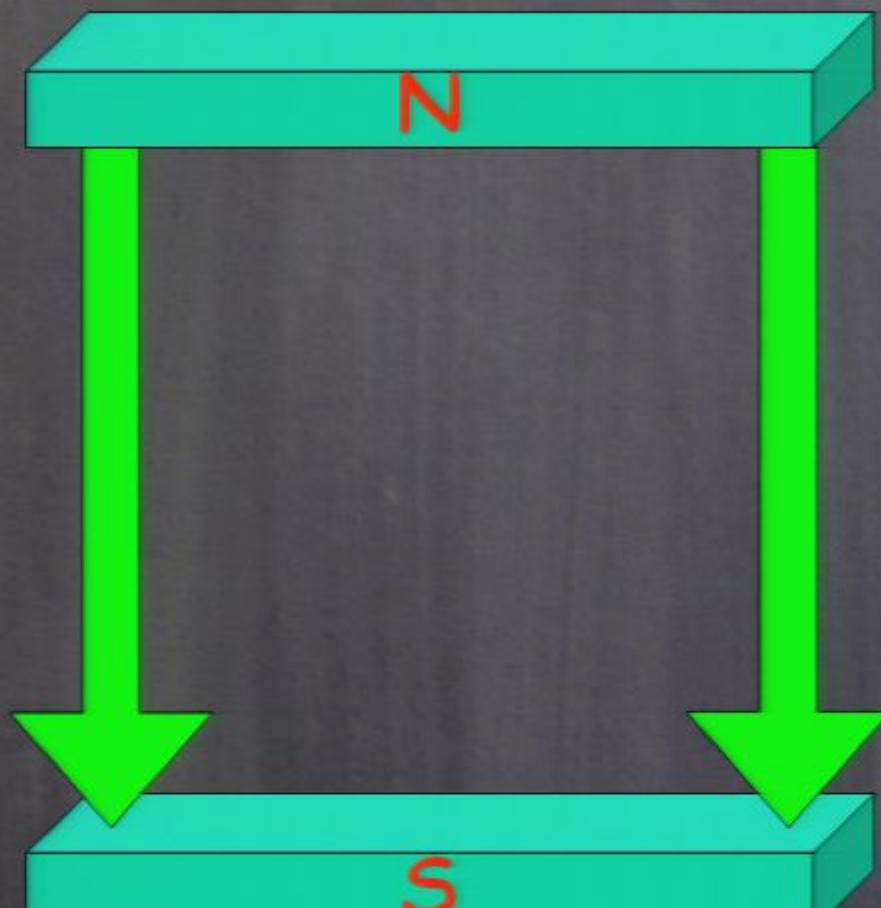
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Field

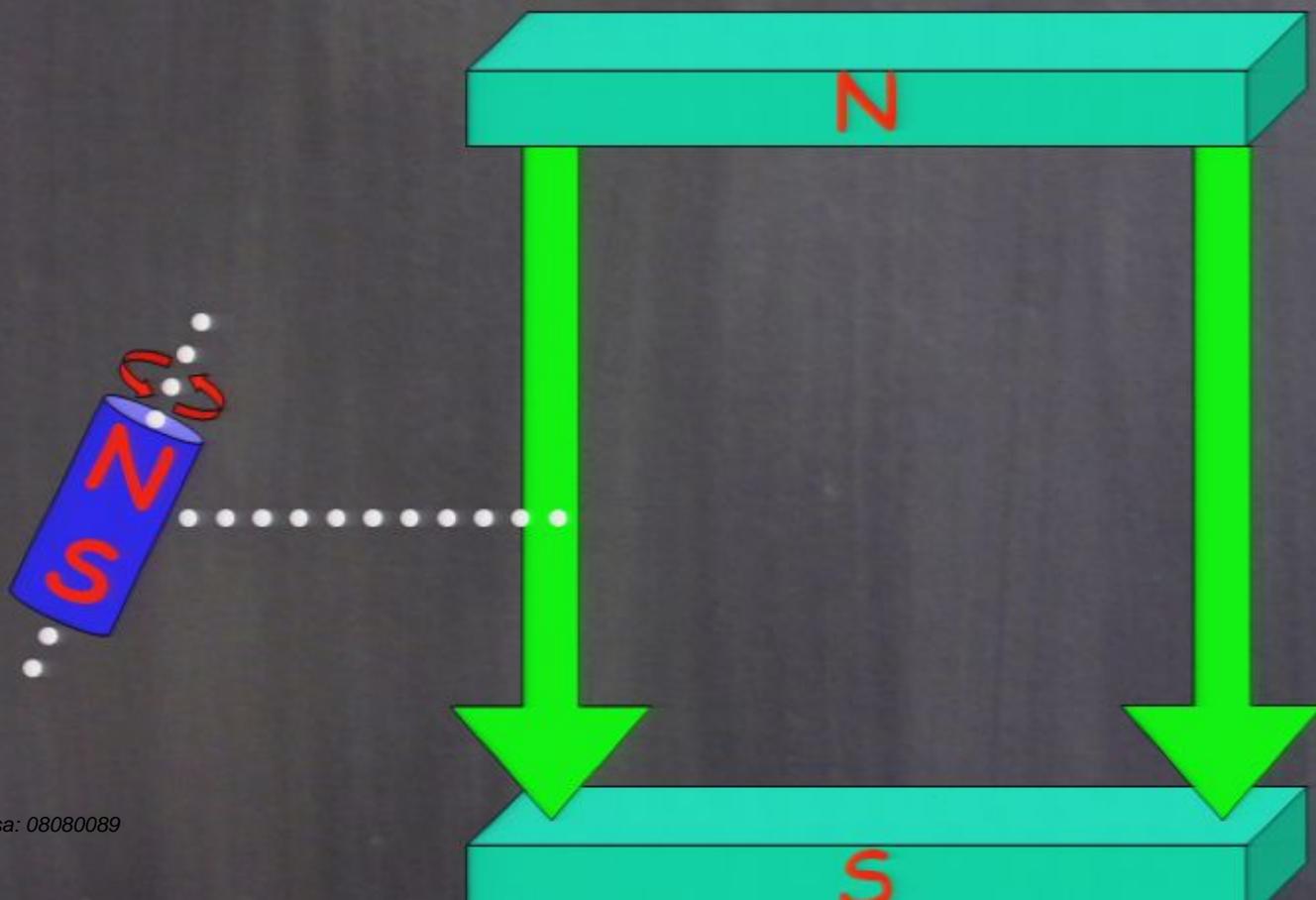
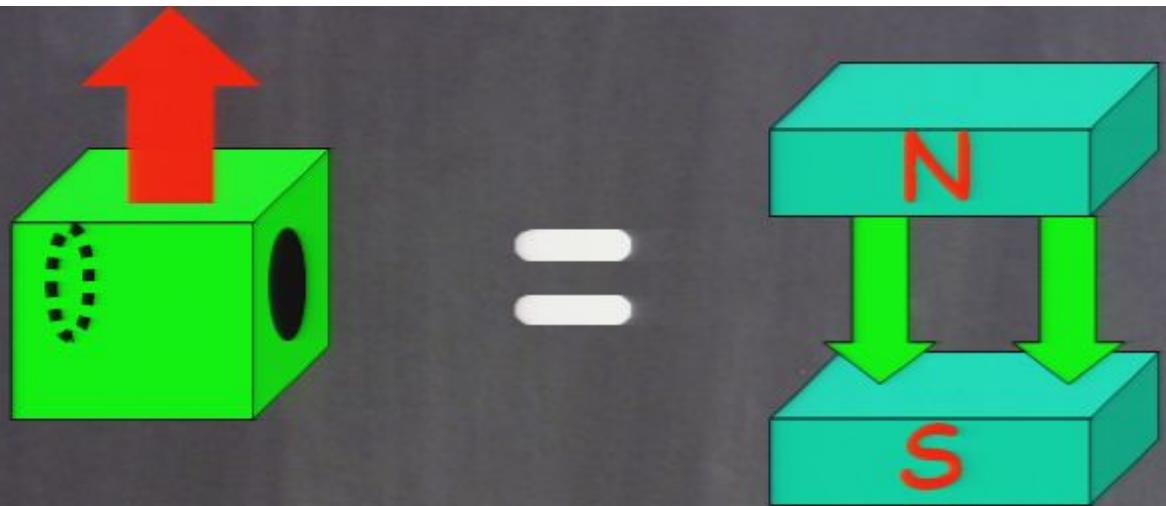


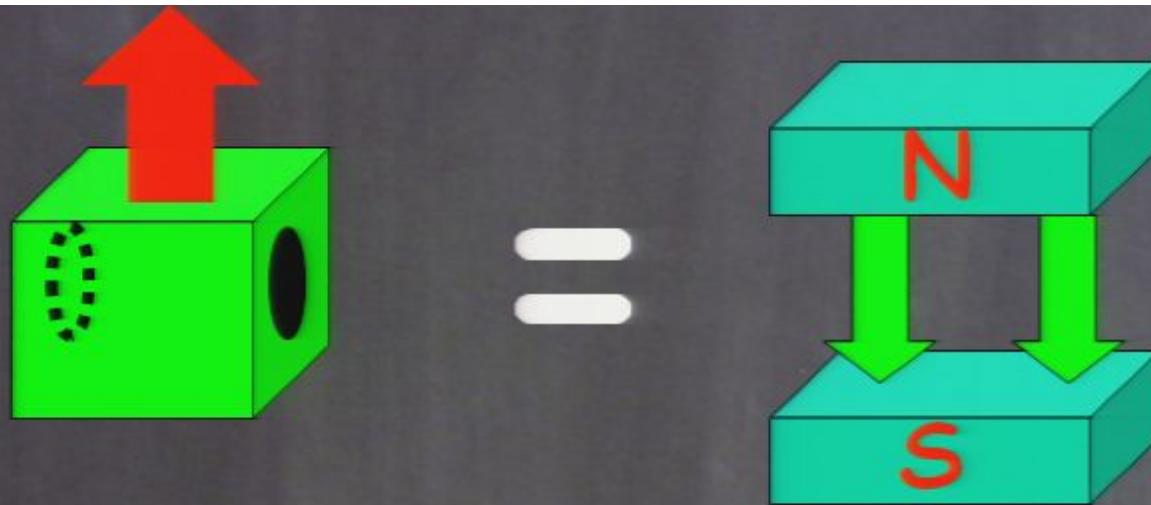
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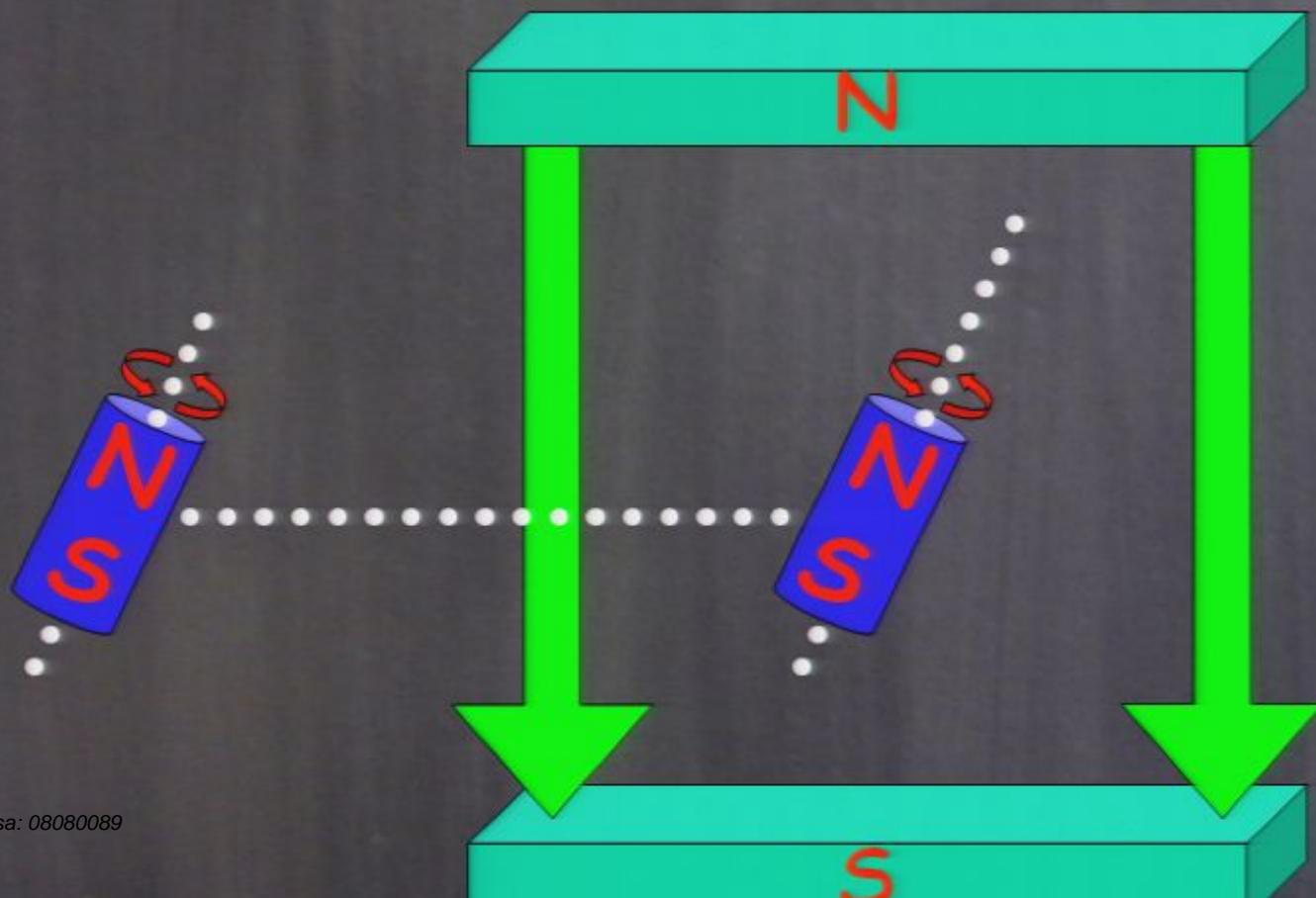
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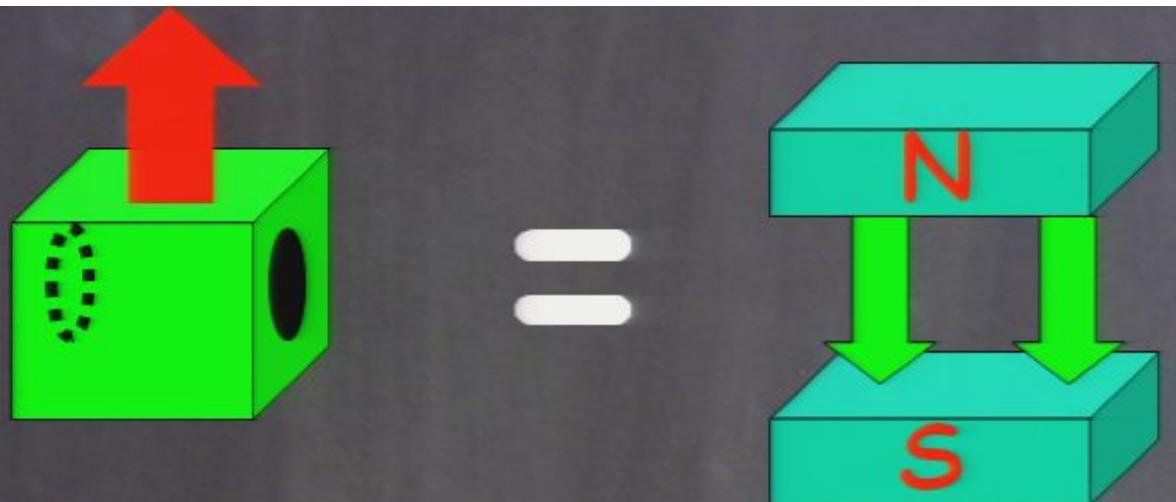




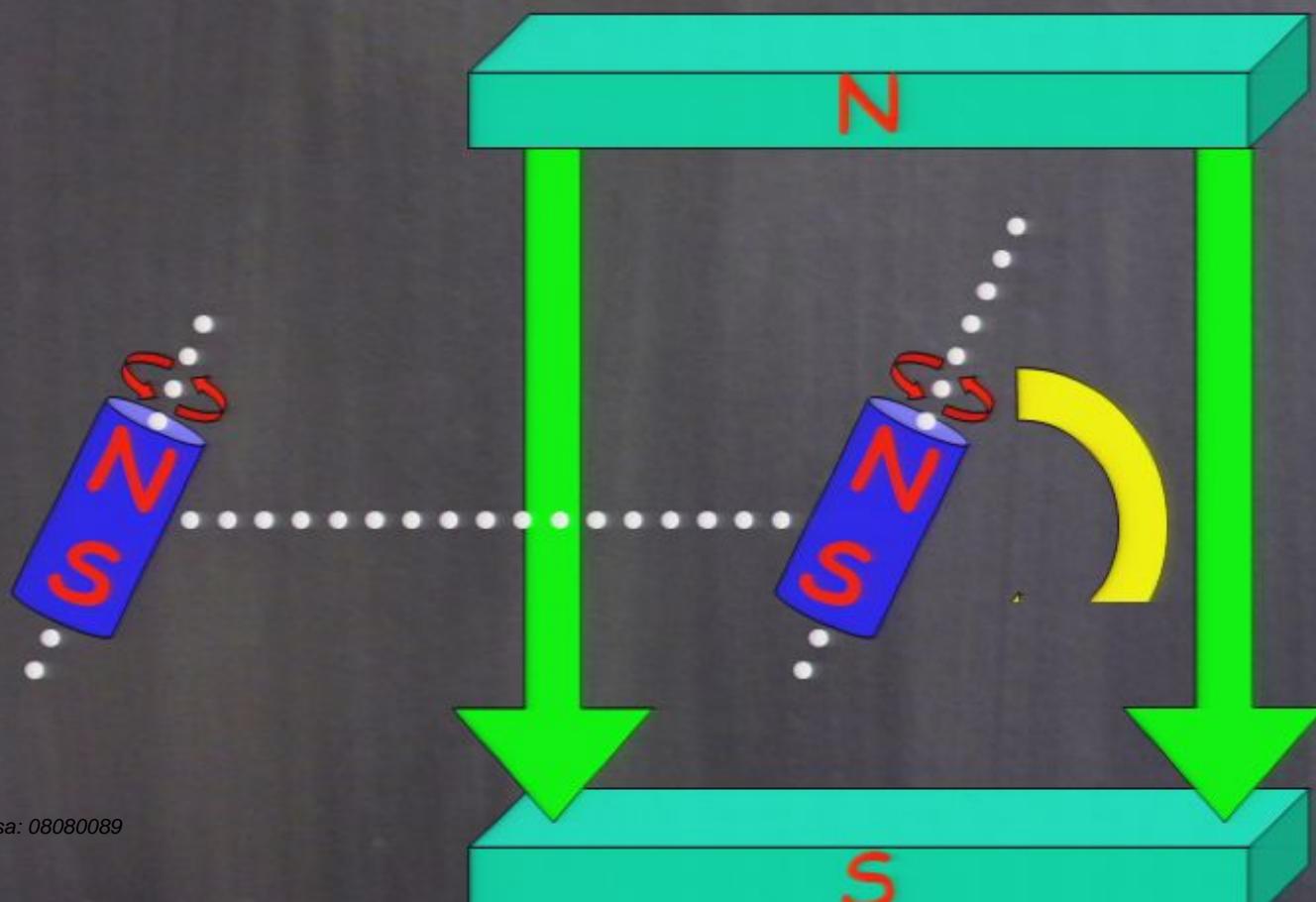


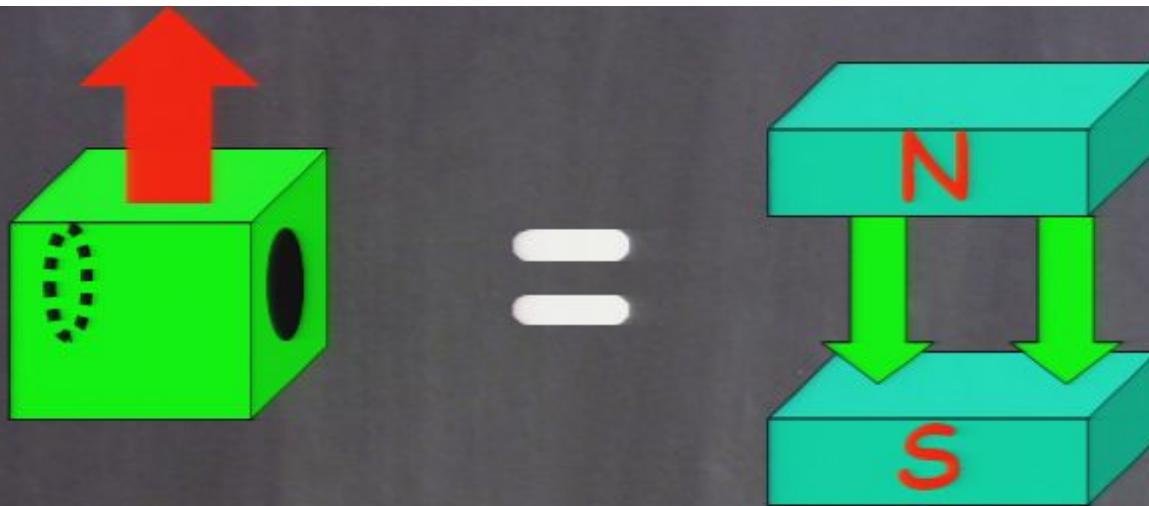
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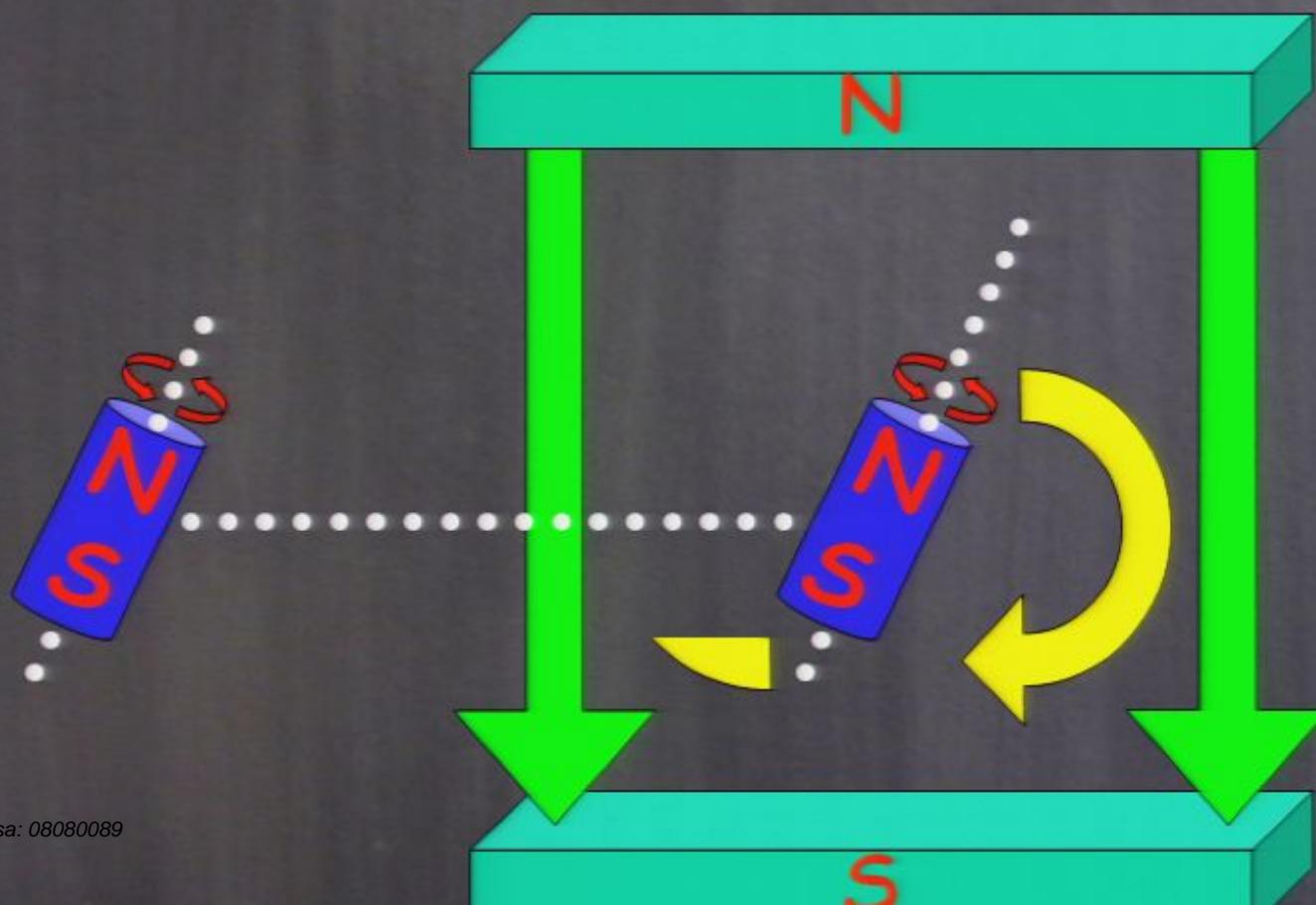


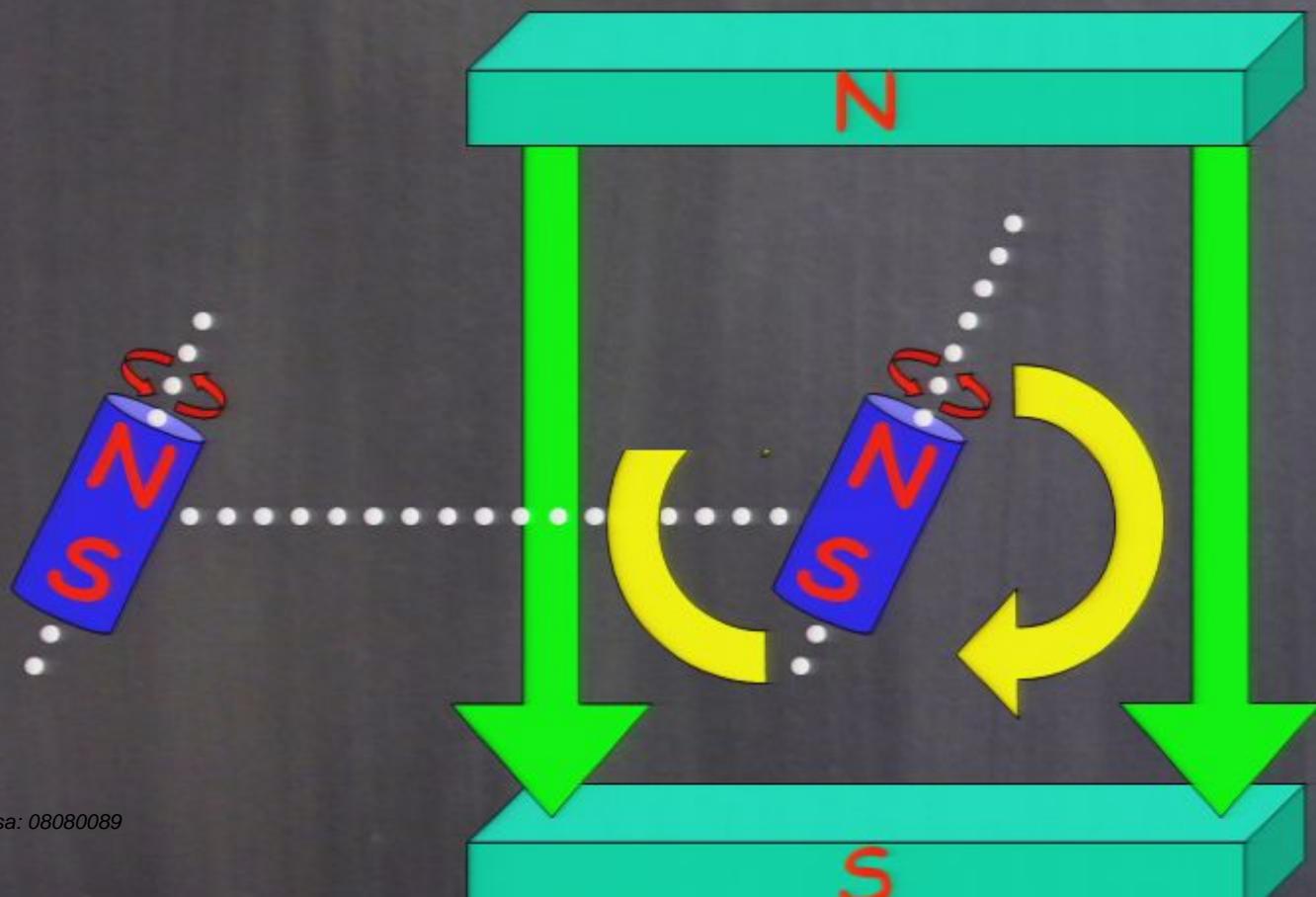
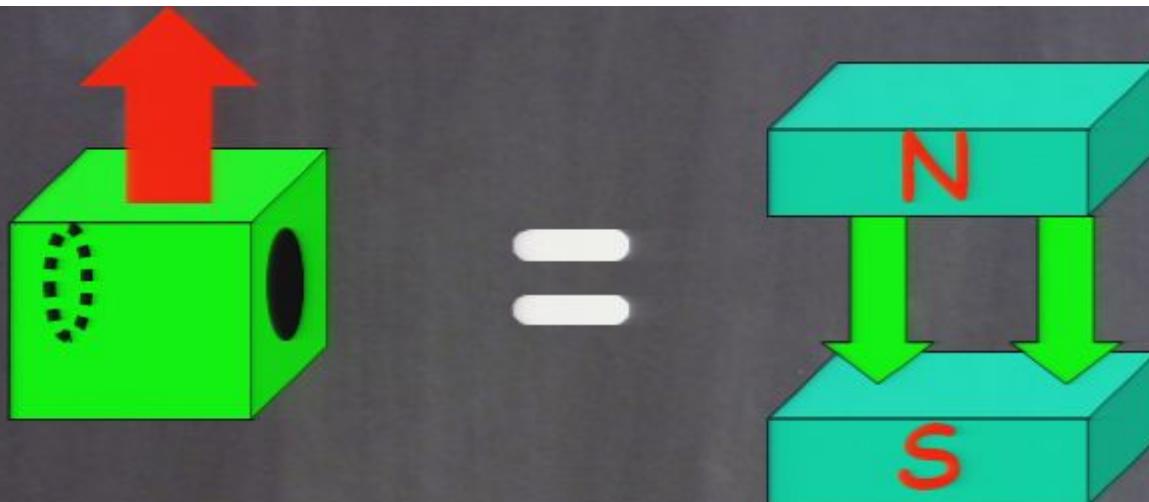
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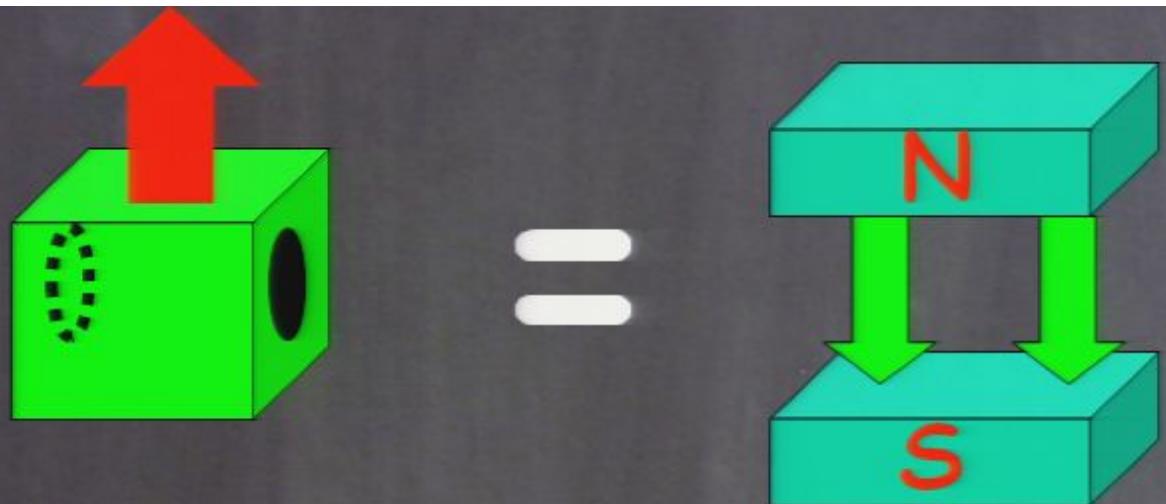




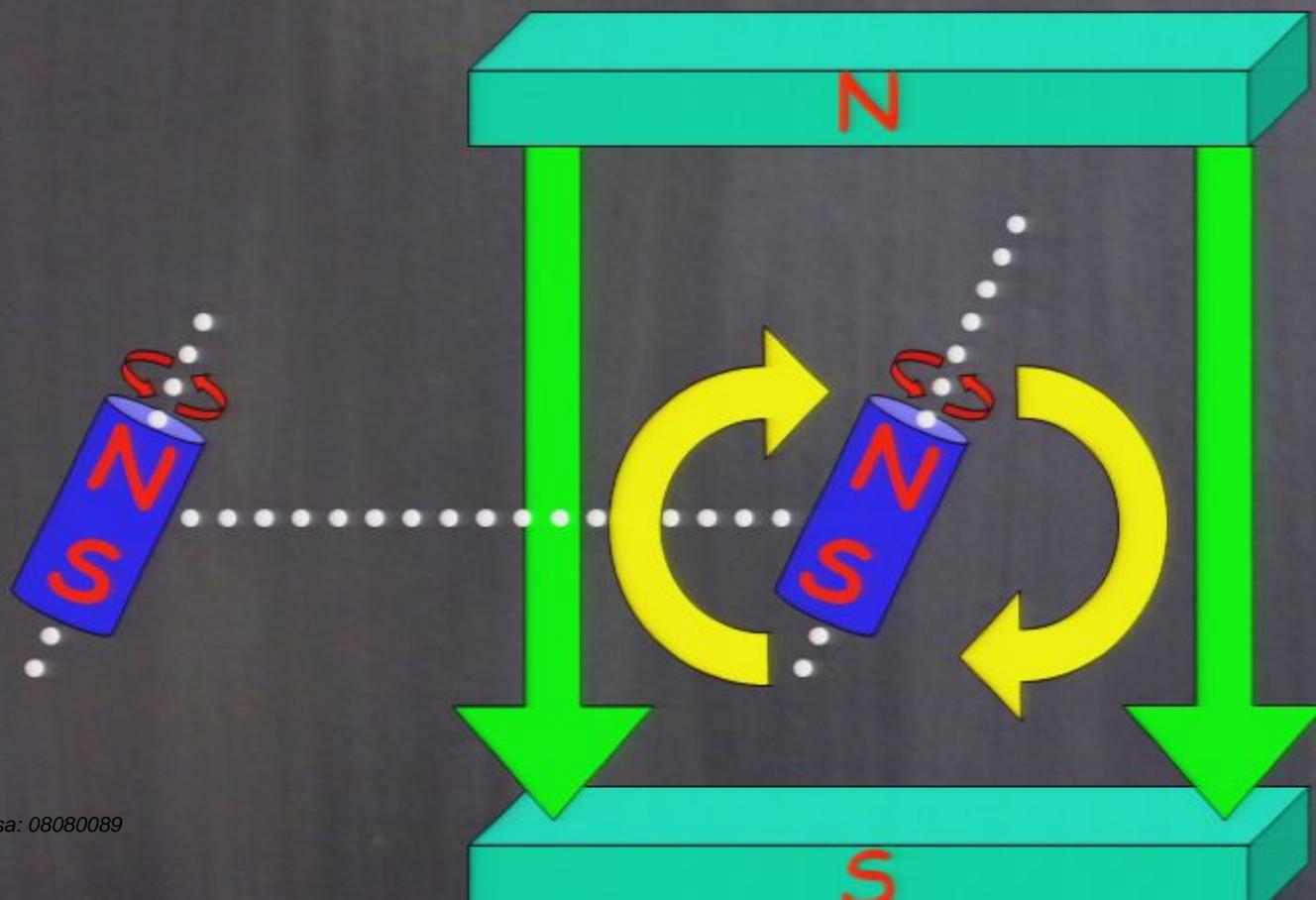
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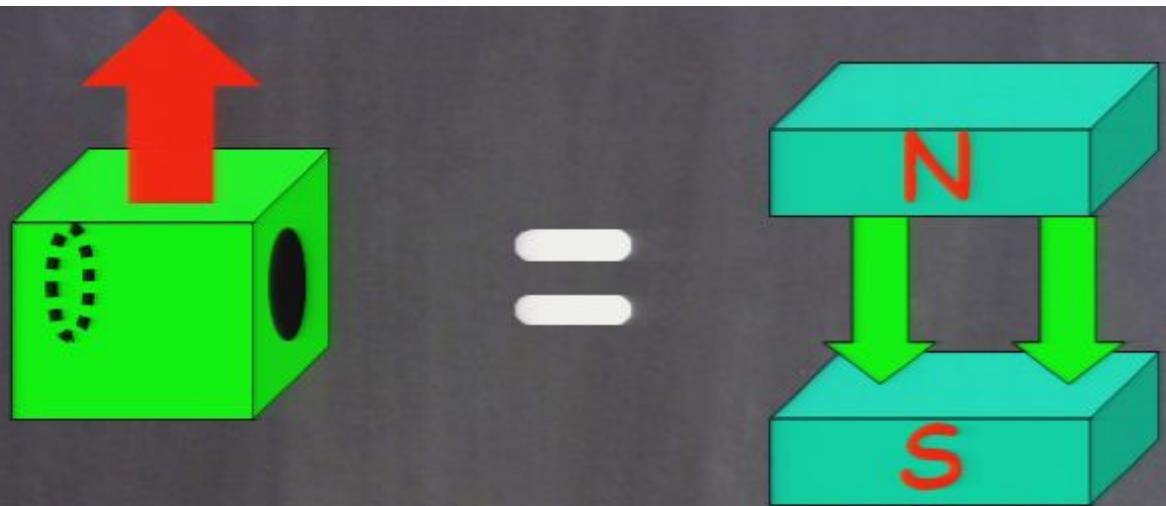




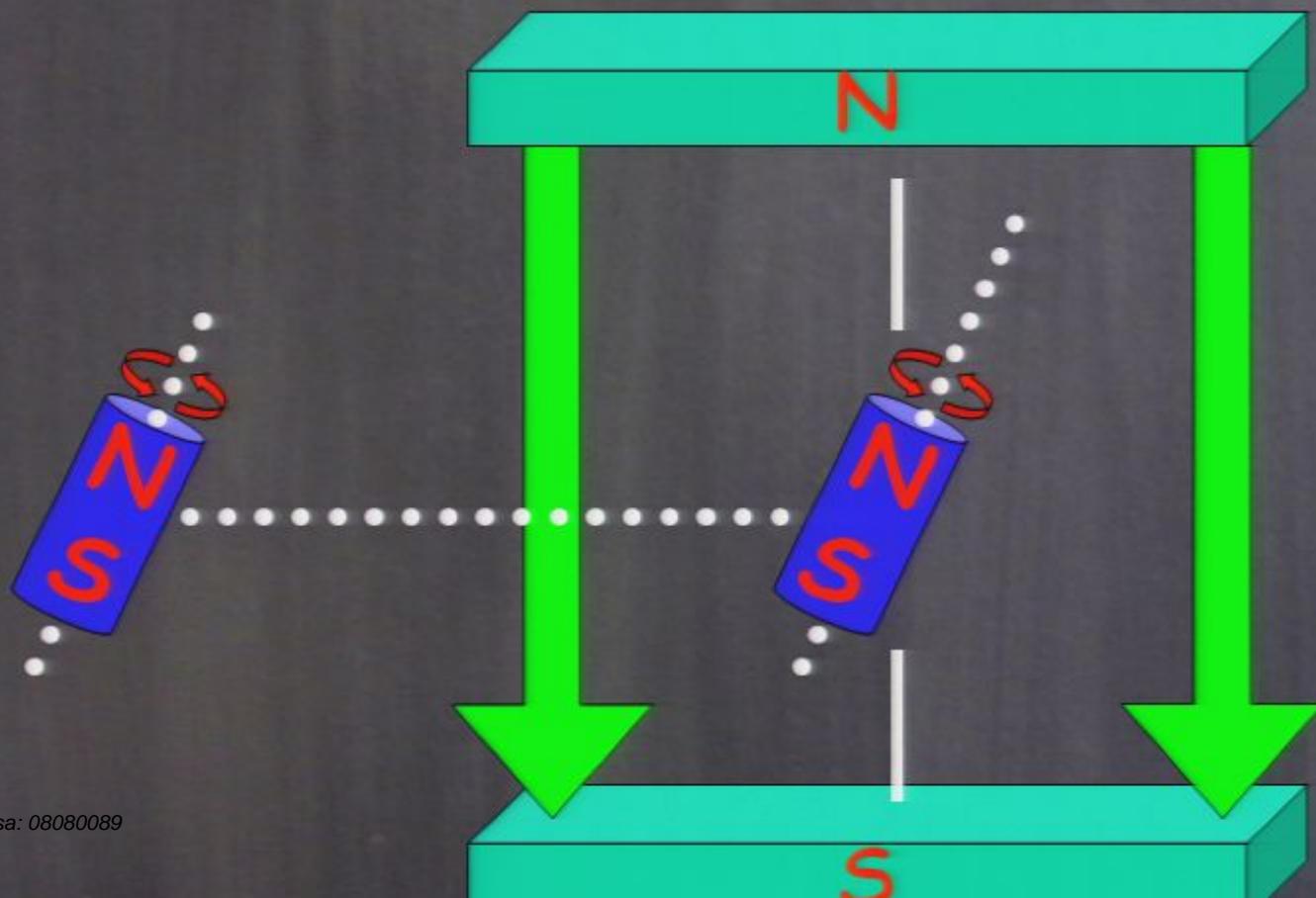


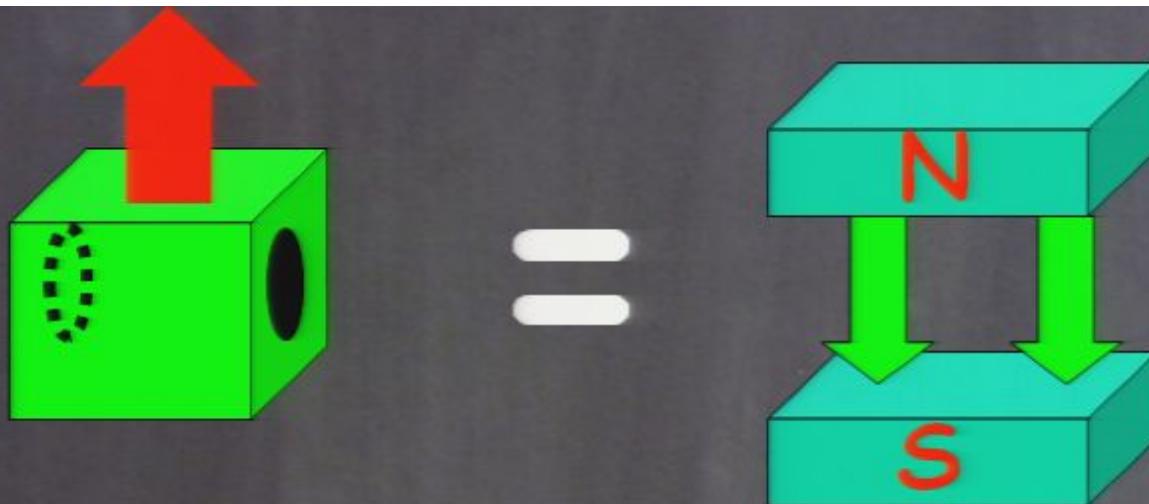
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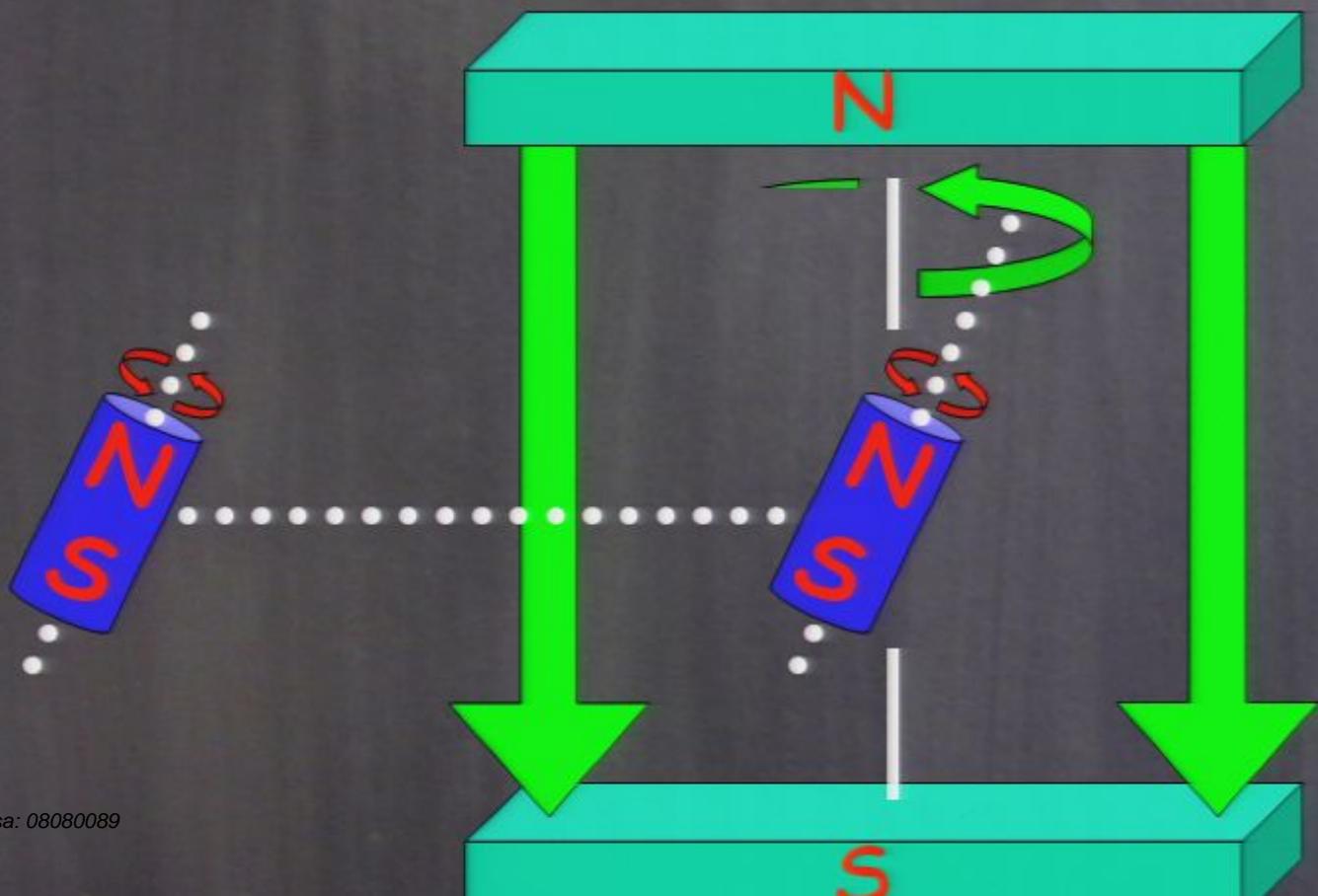


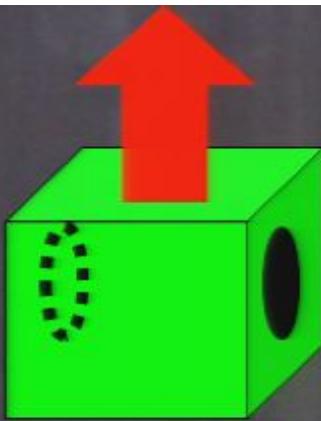
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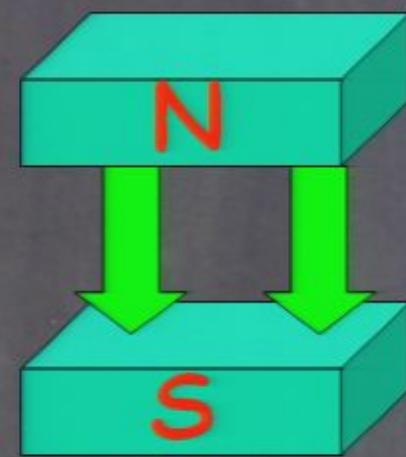


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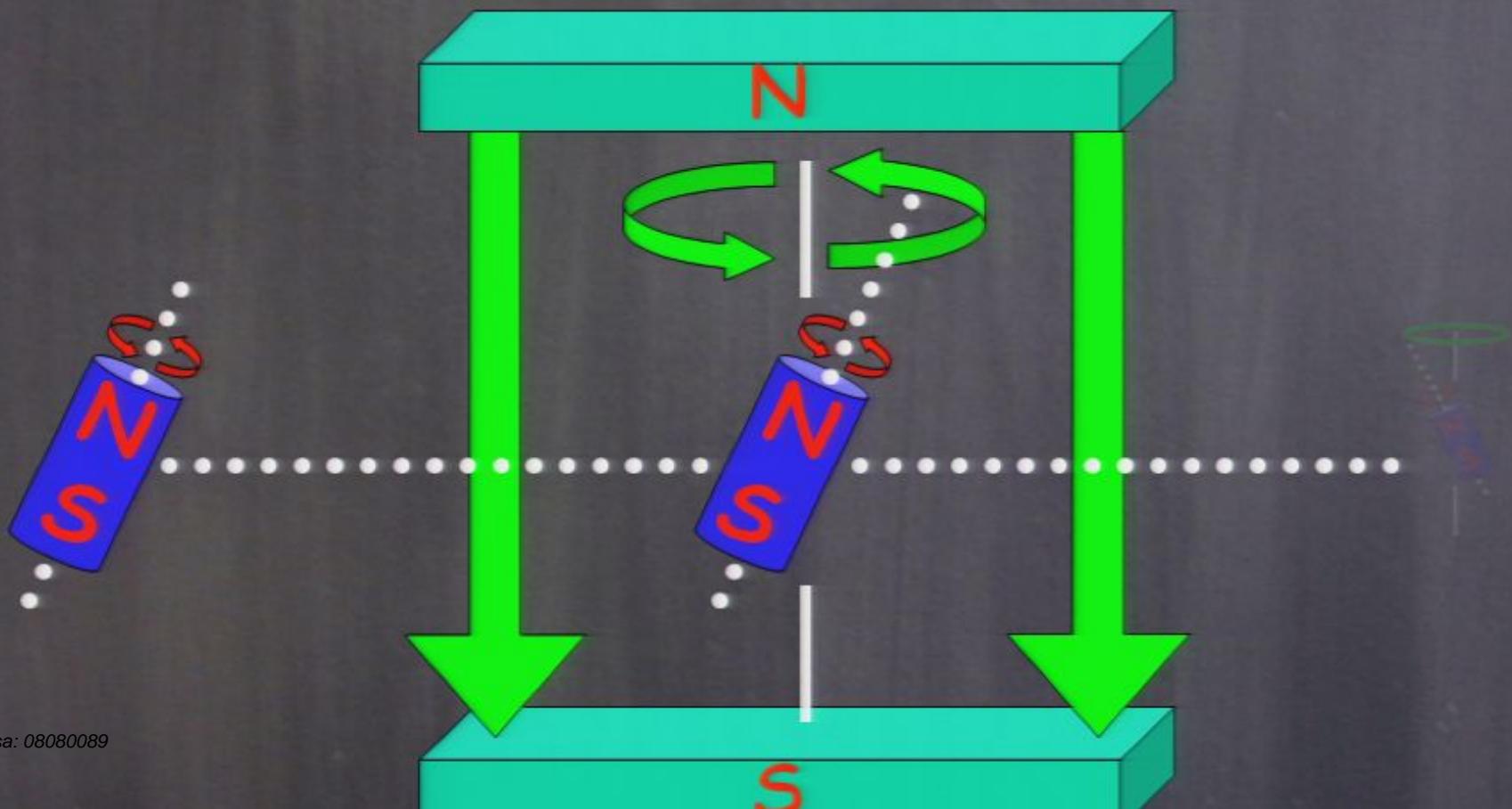


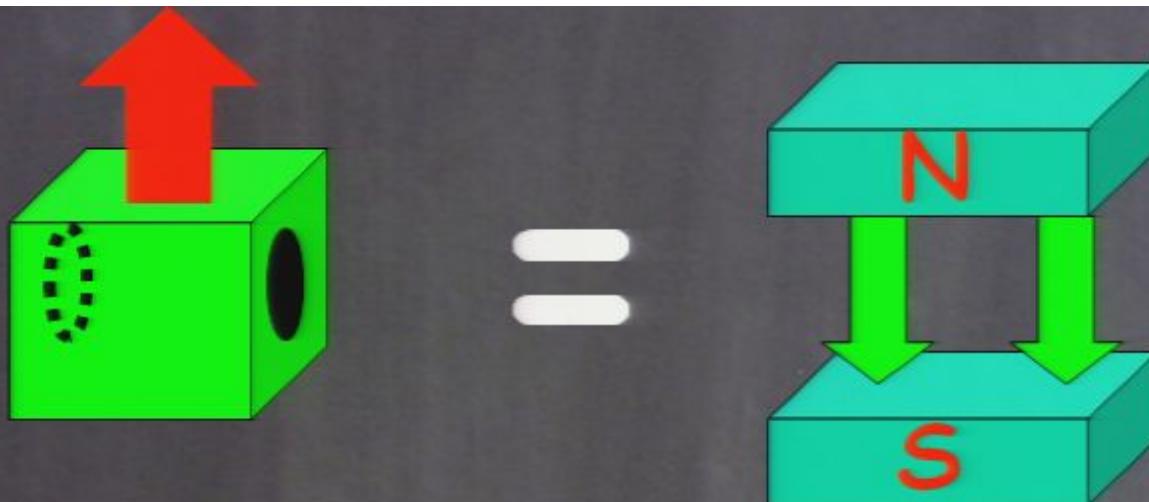


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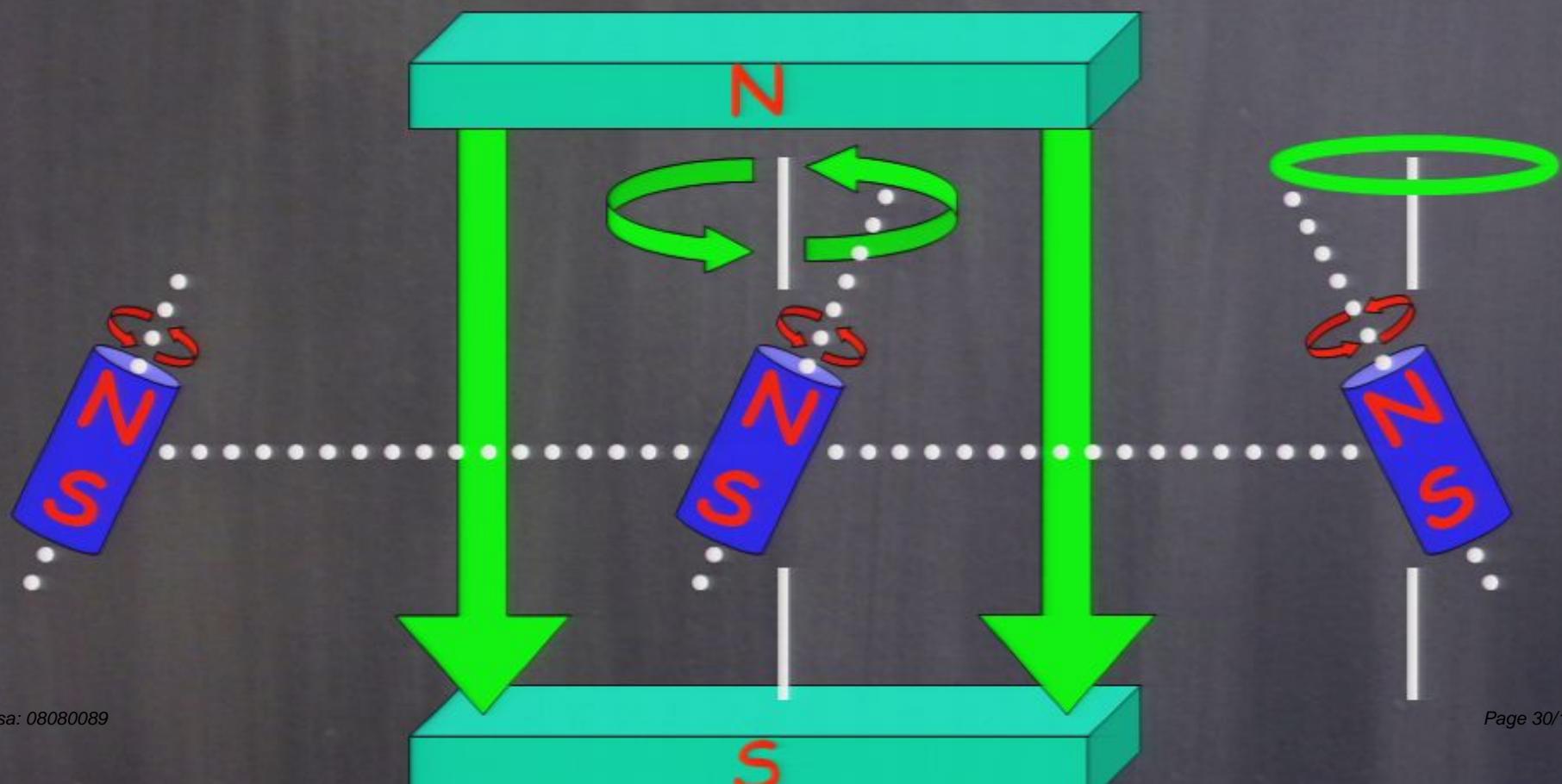


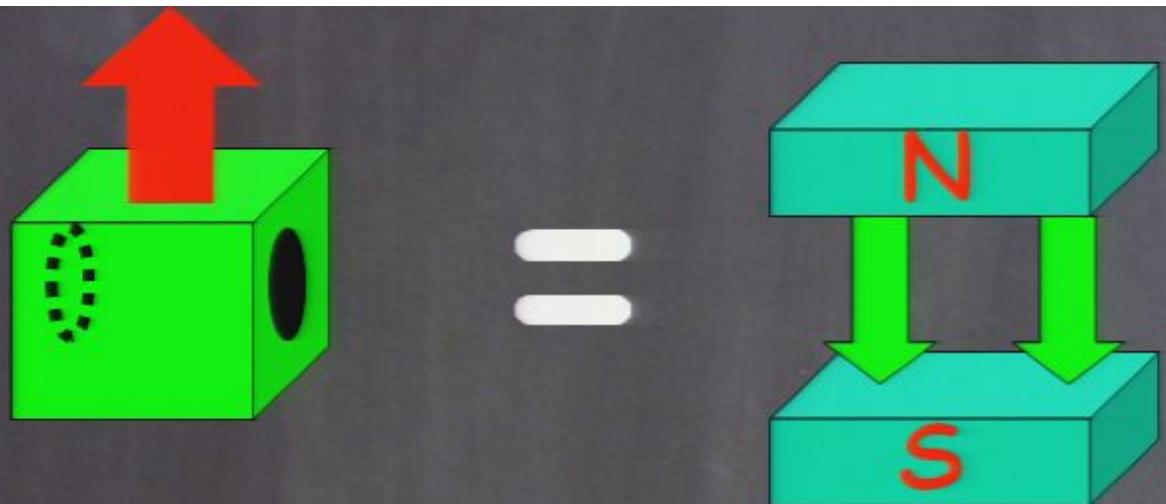
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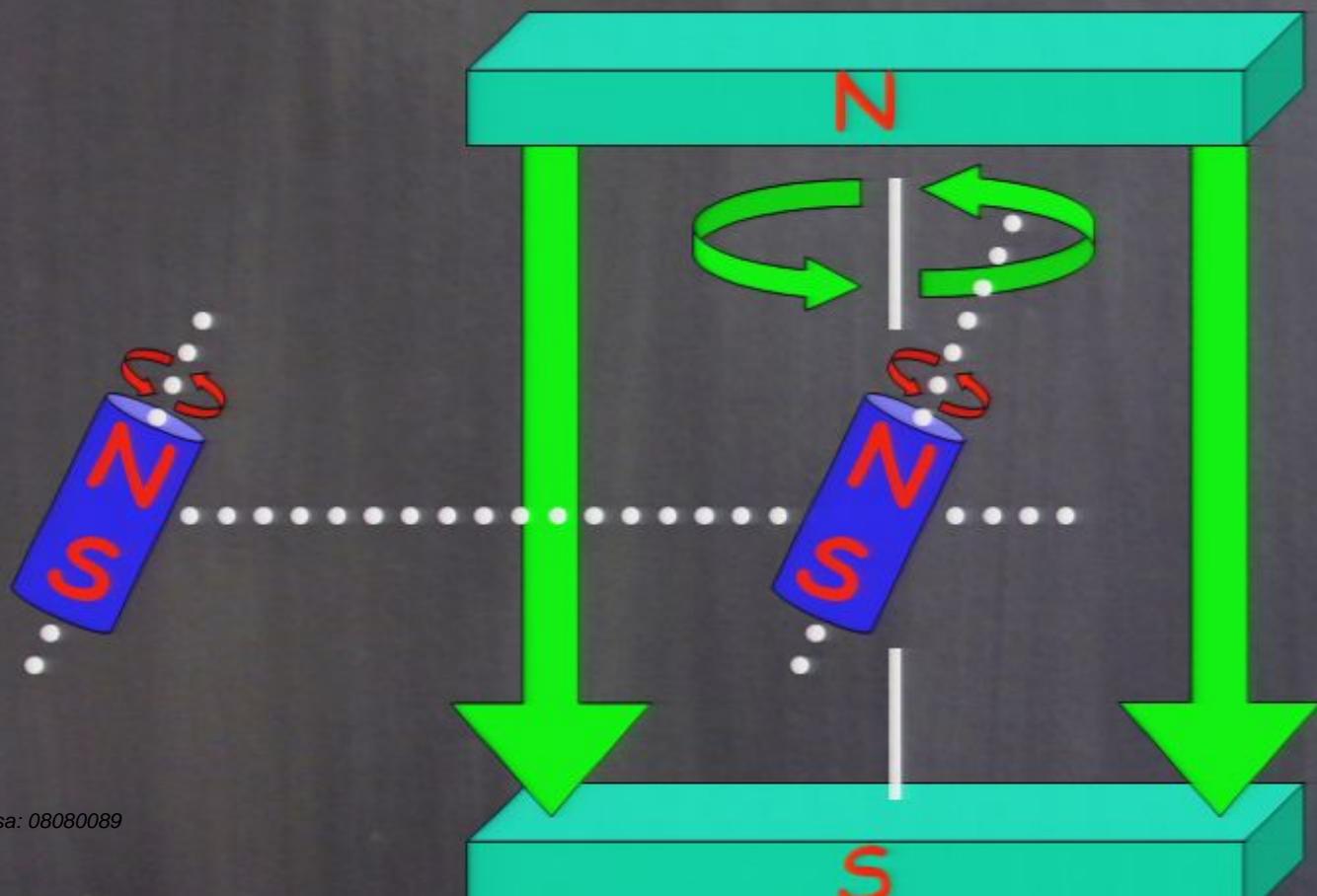


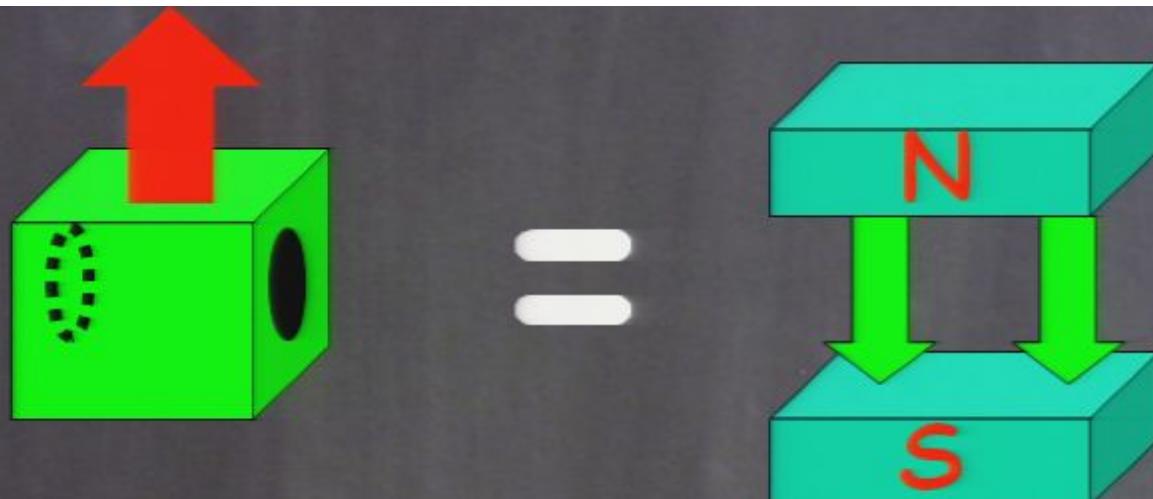
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Magnetic  
Field



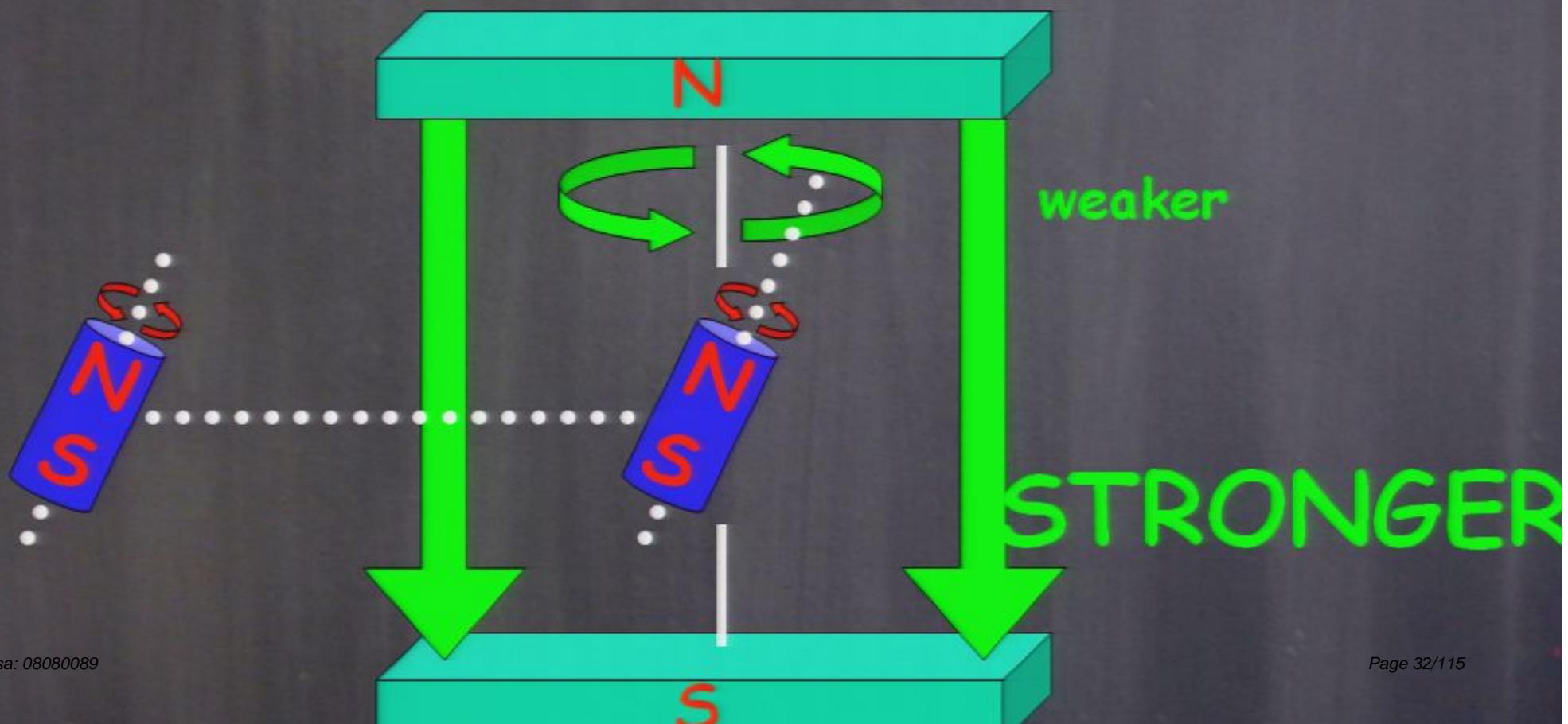


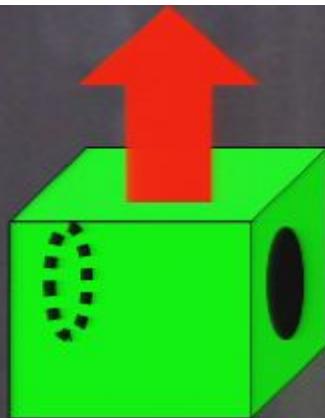
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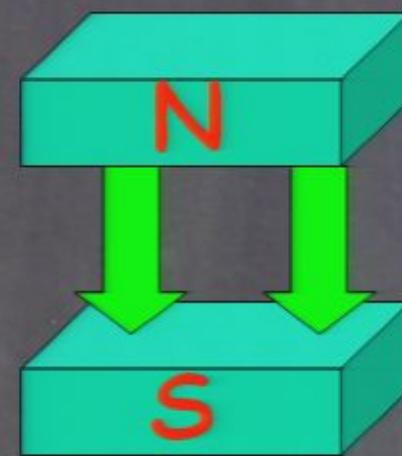


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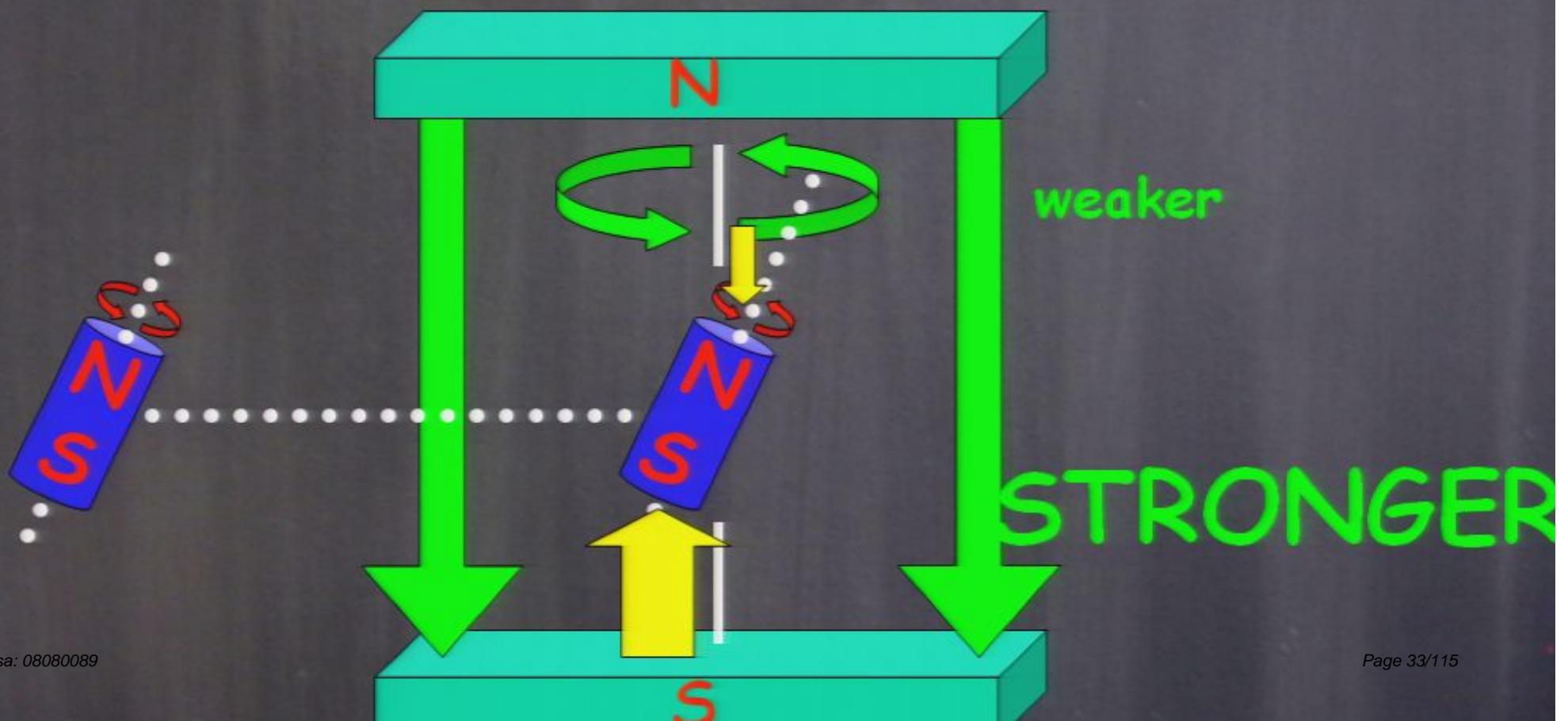


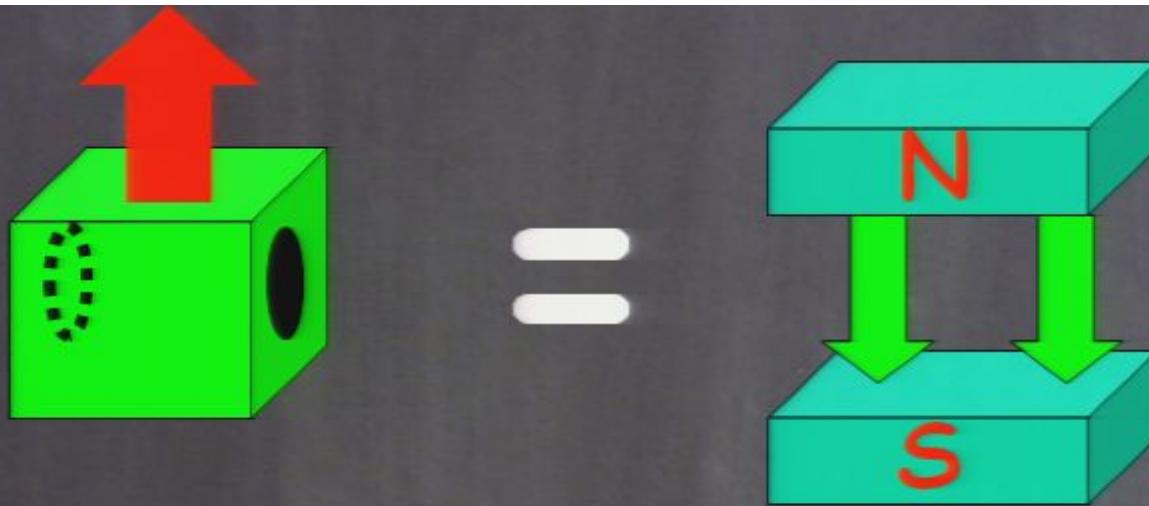


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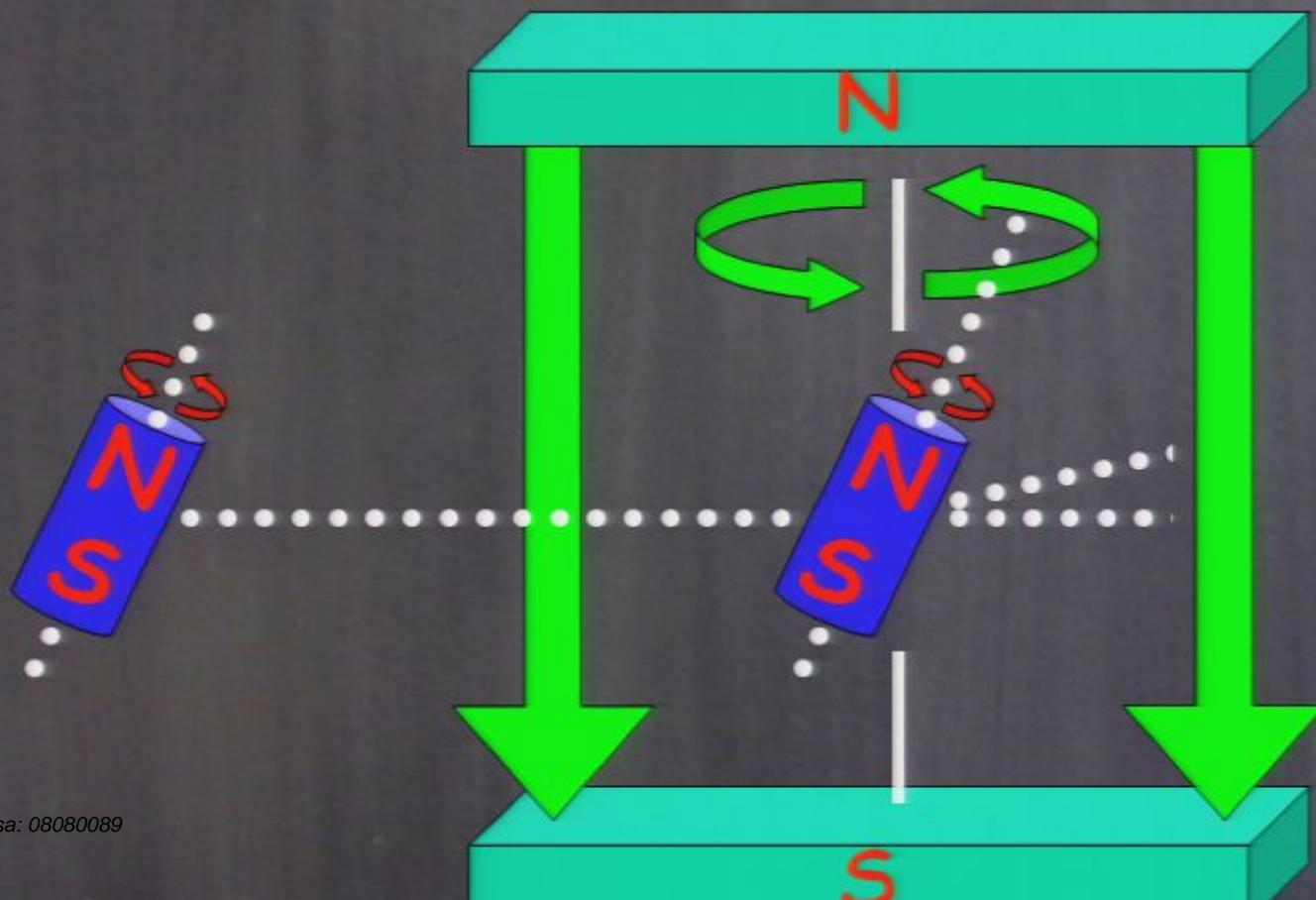


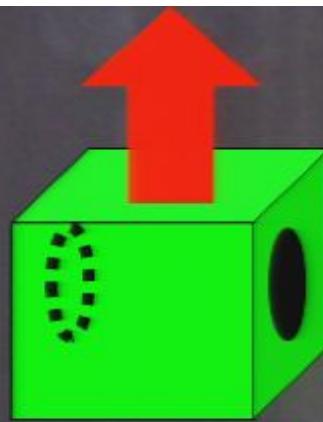
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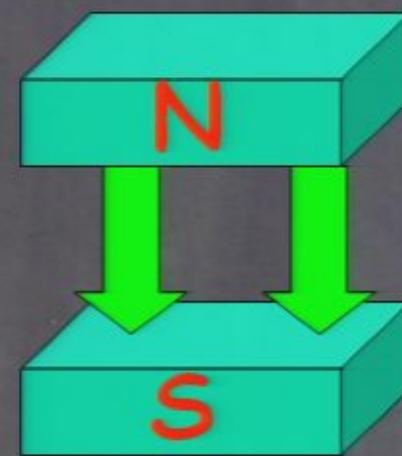


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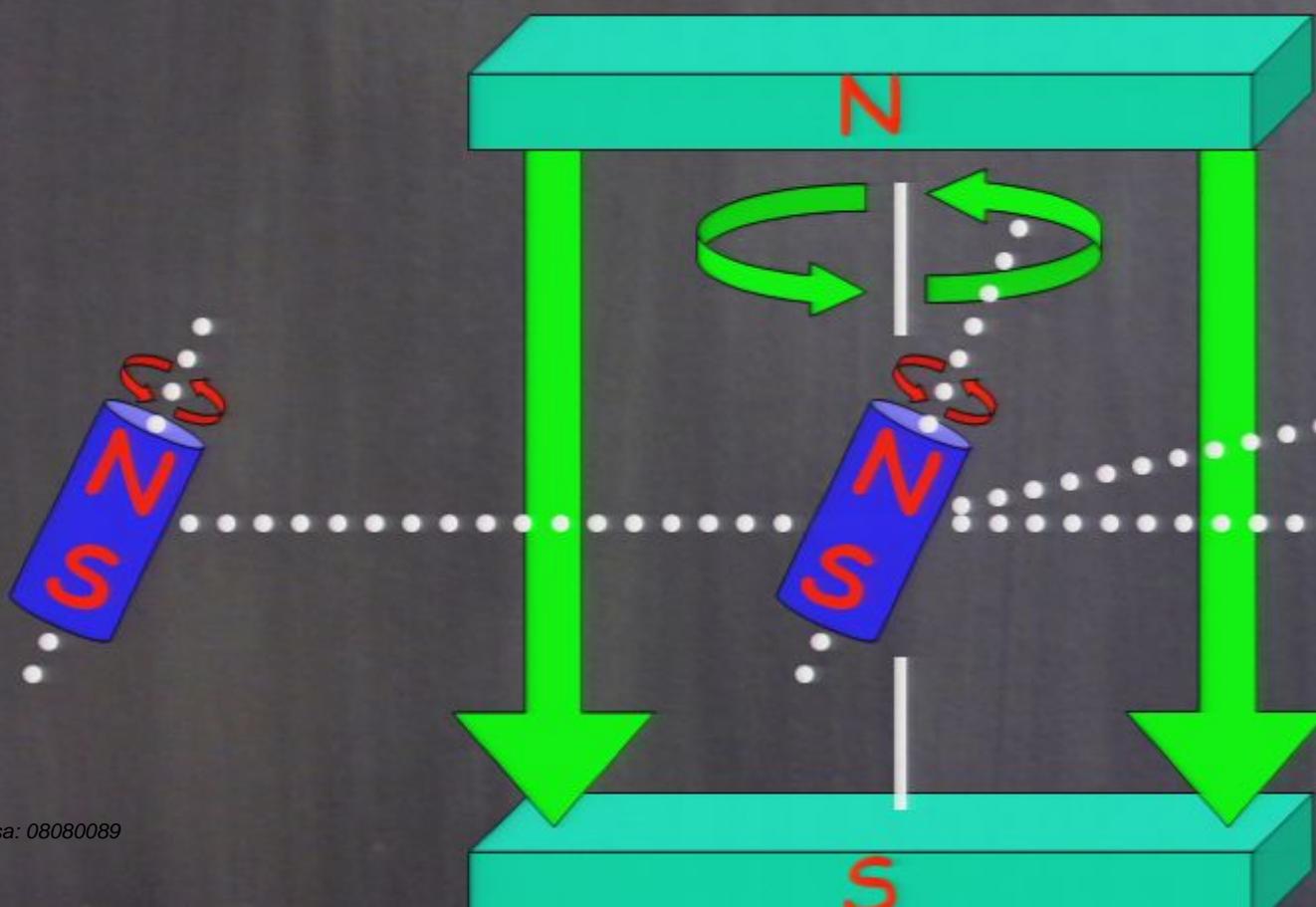




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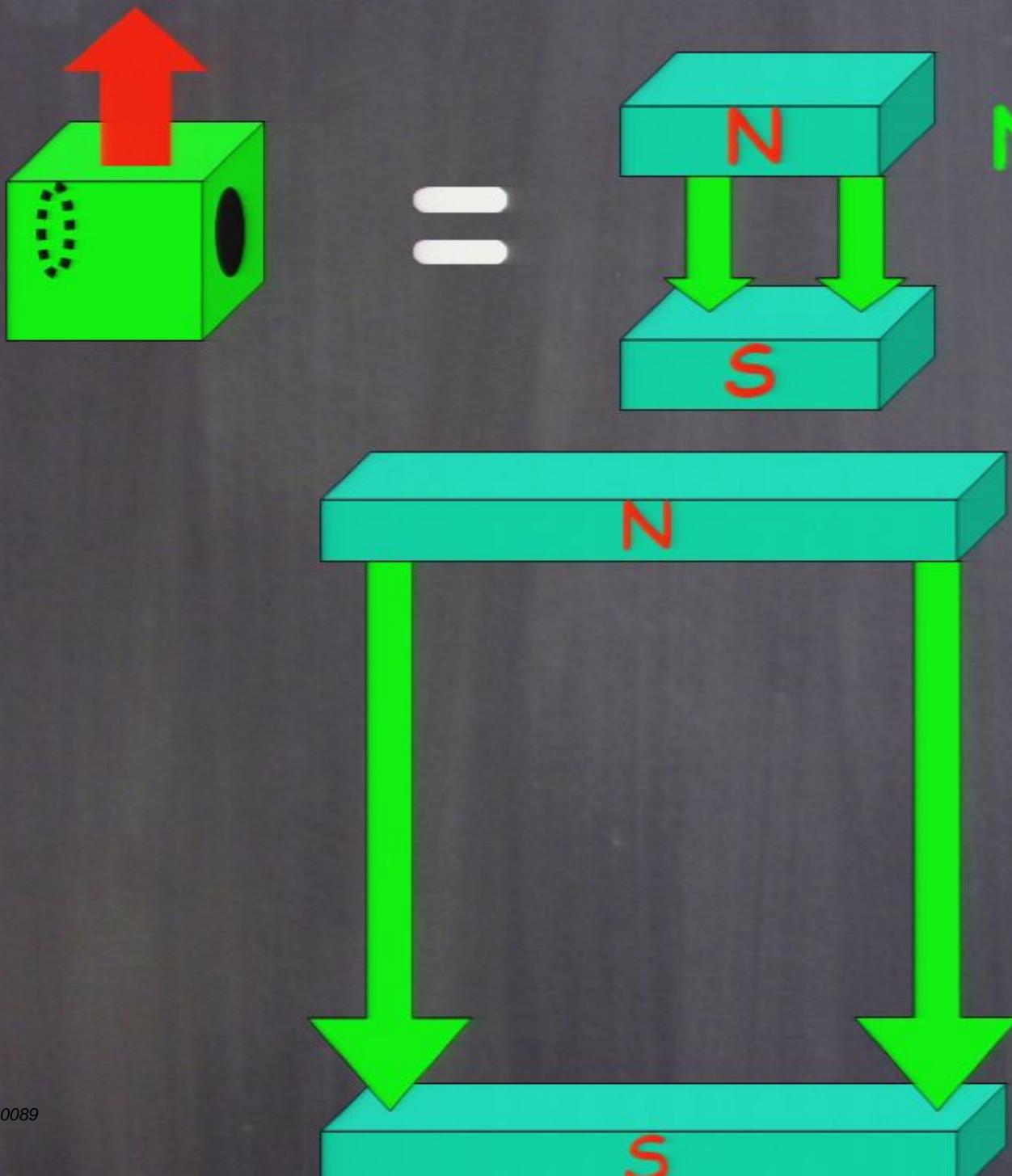


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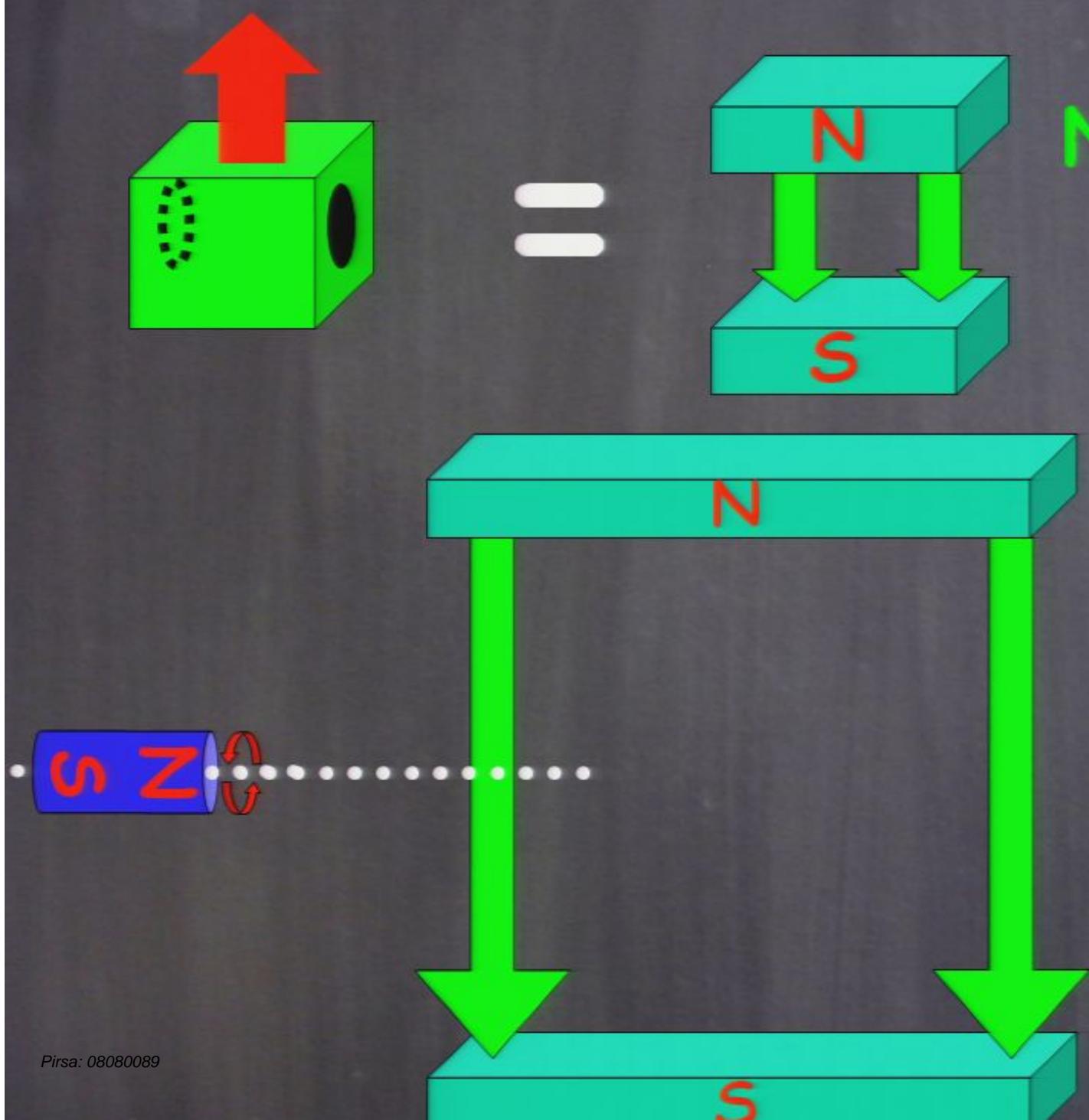


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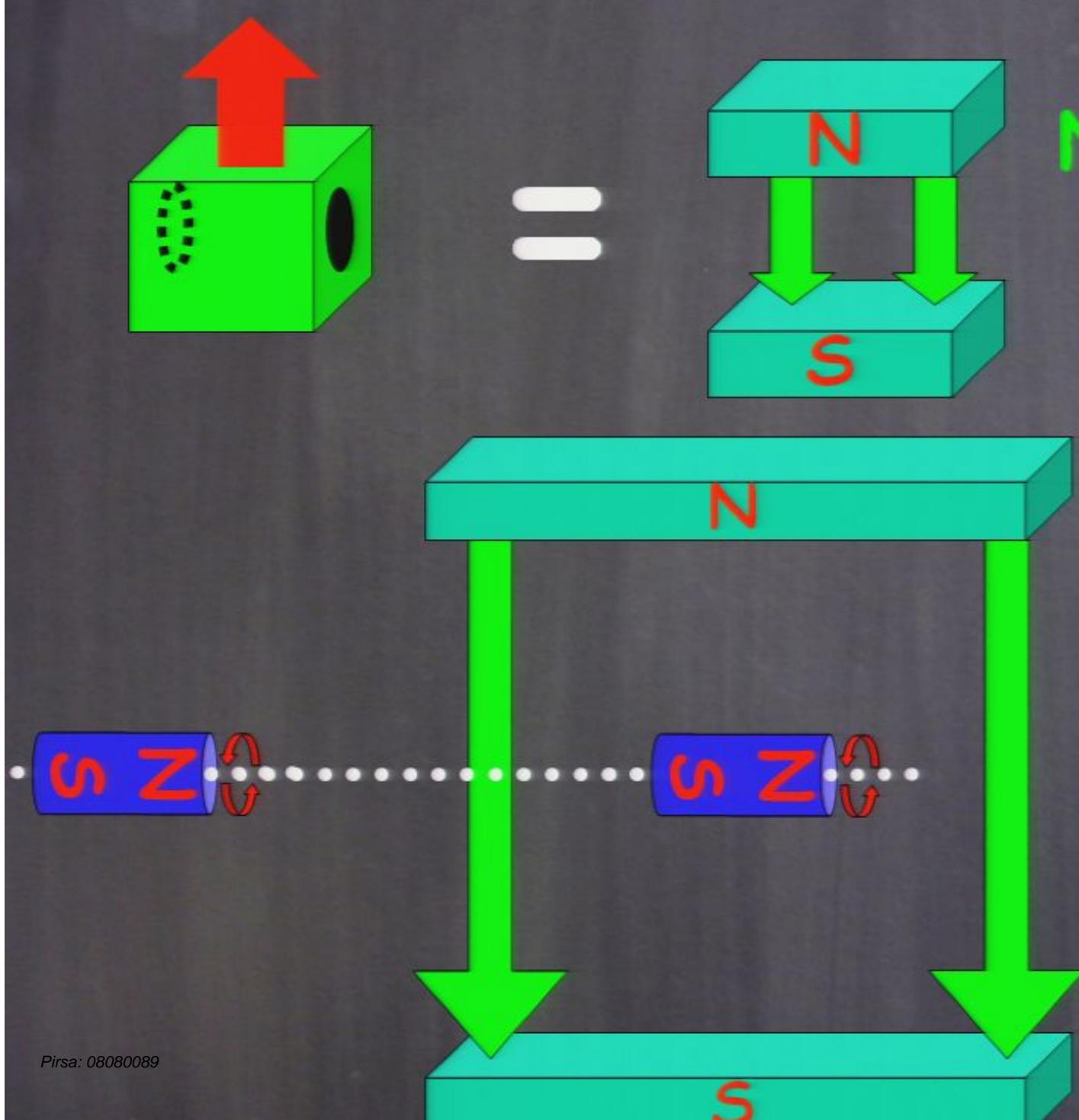
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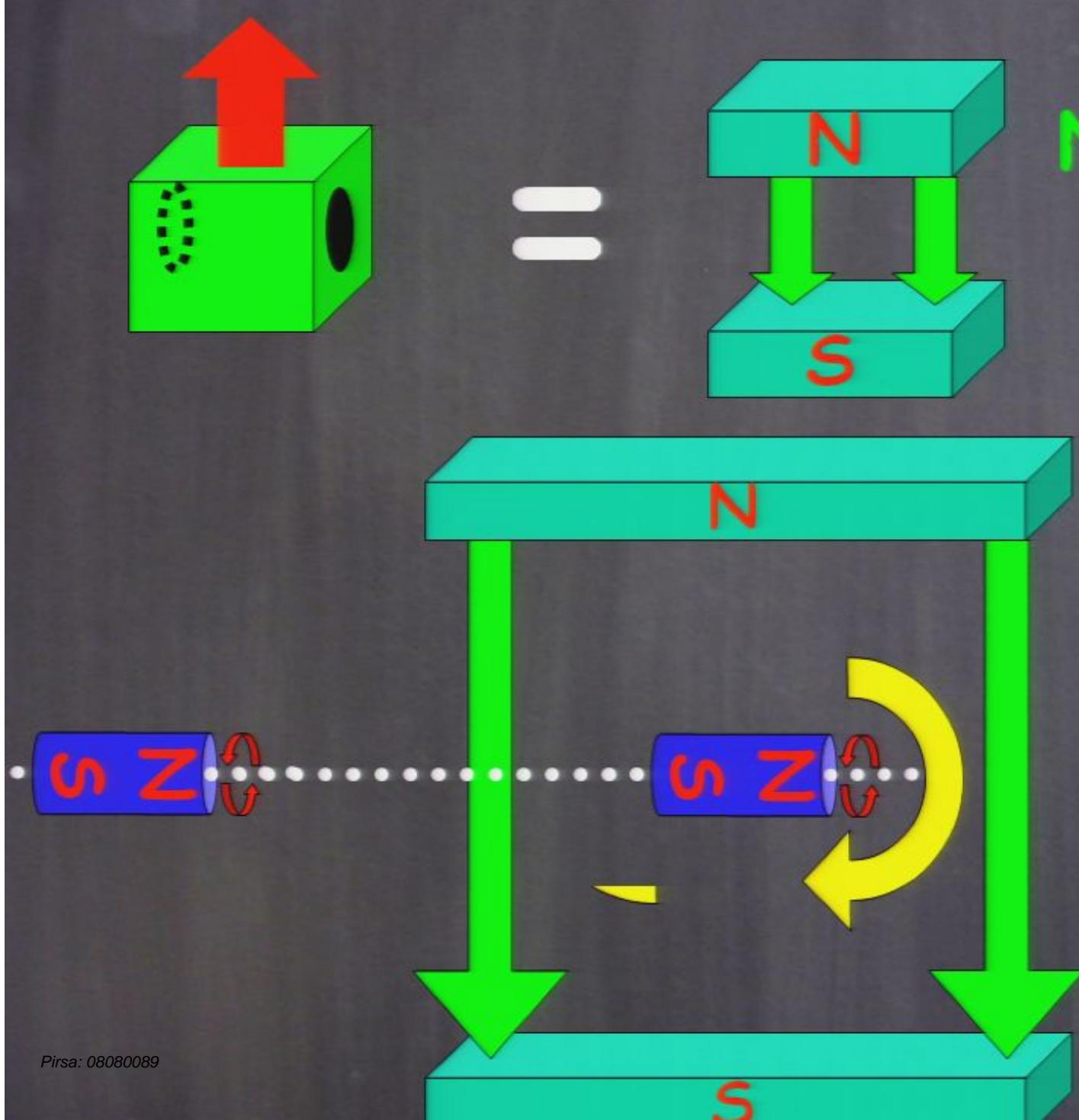
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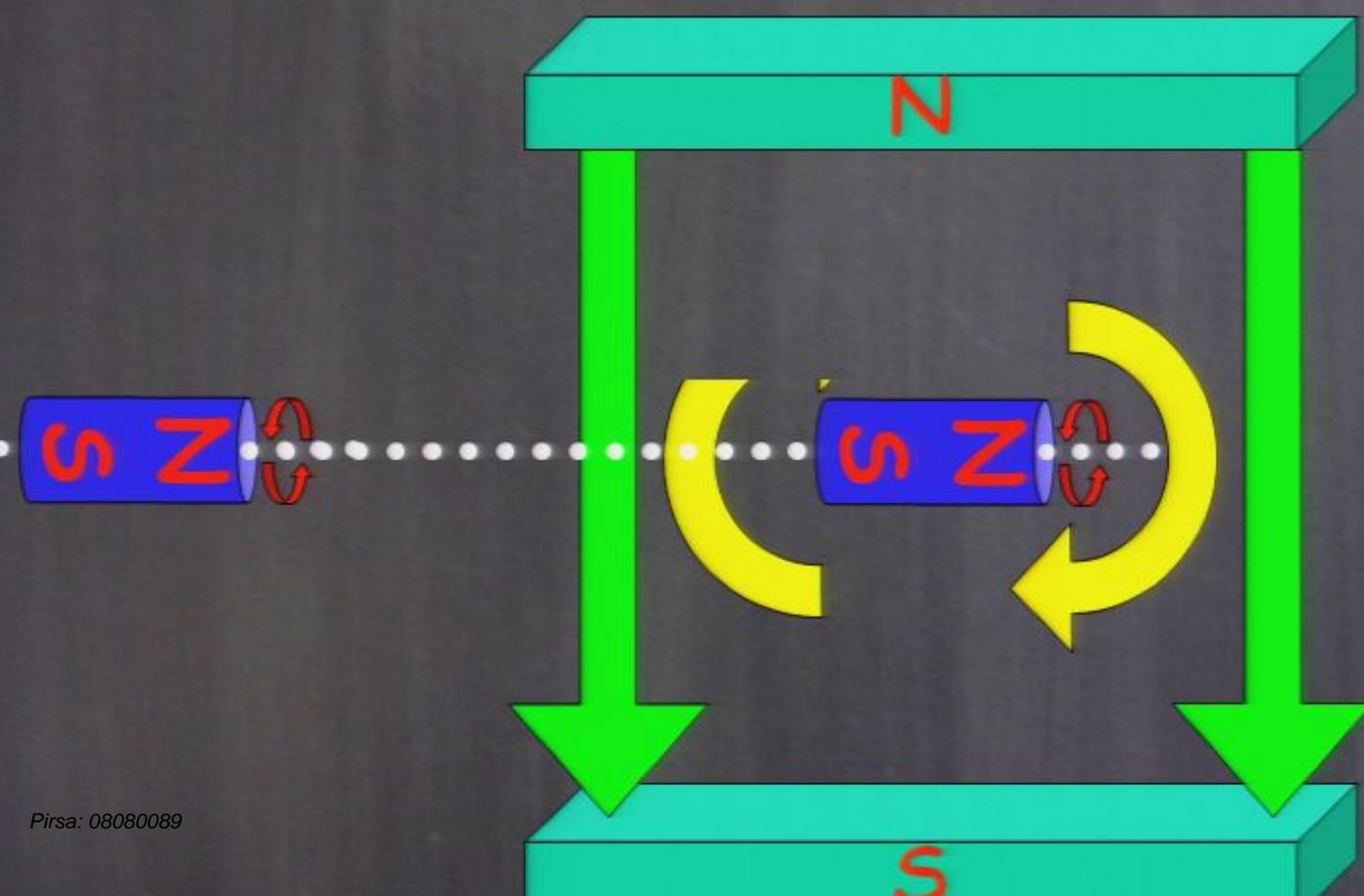
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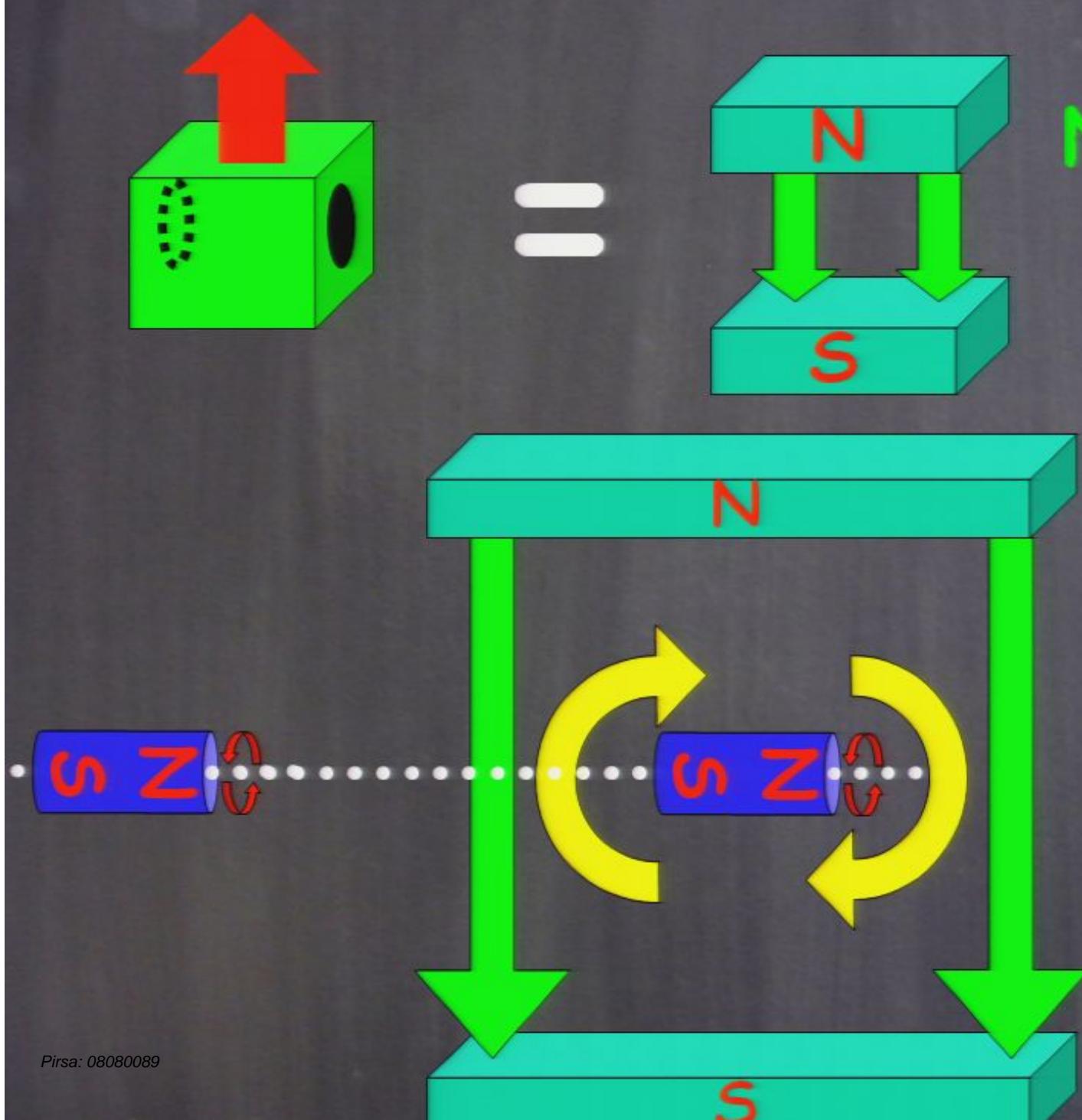
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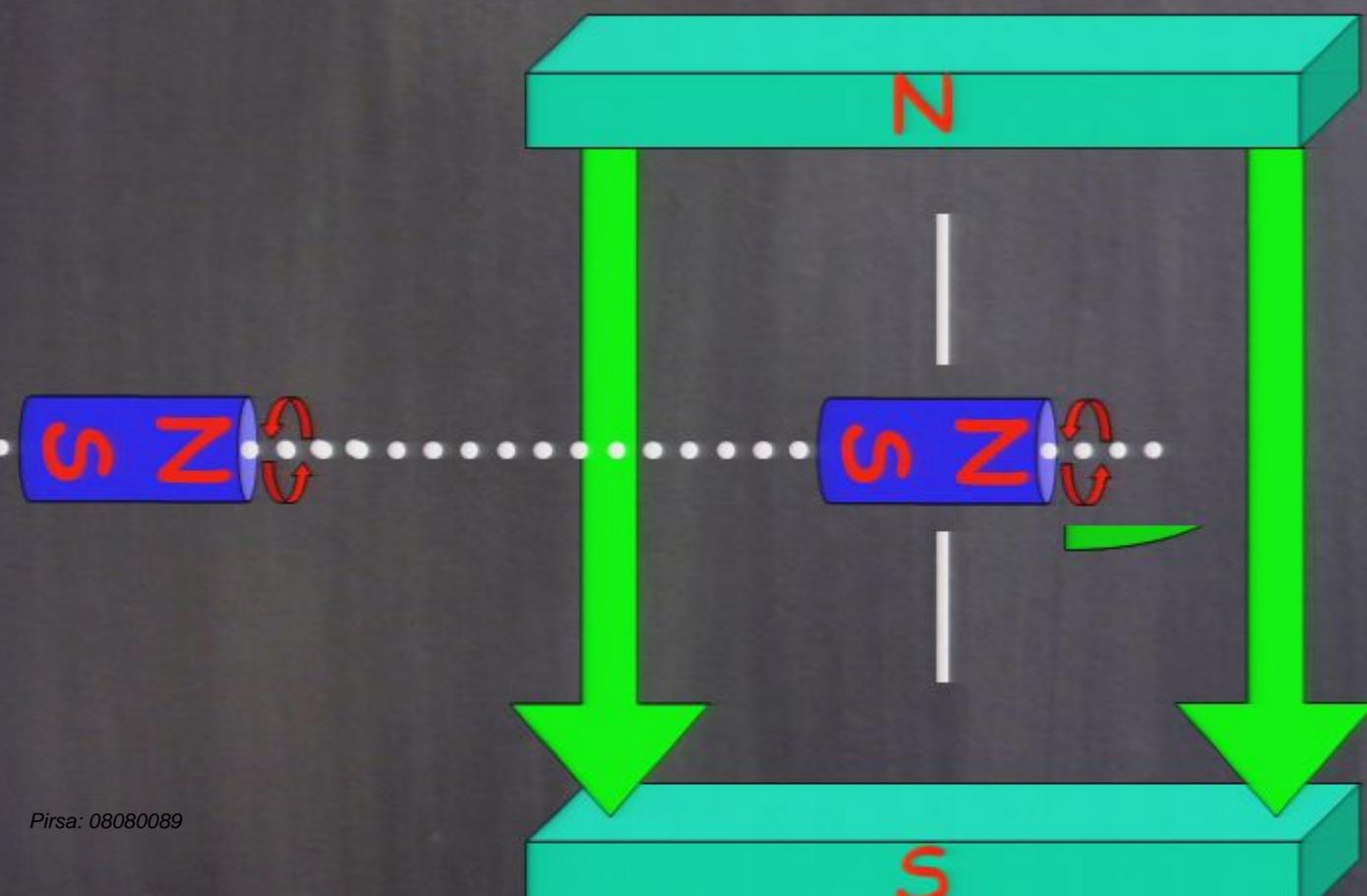
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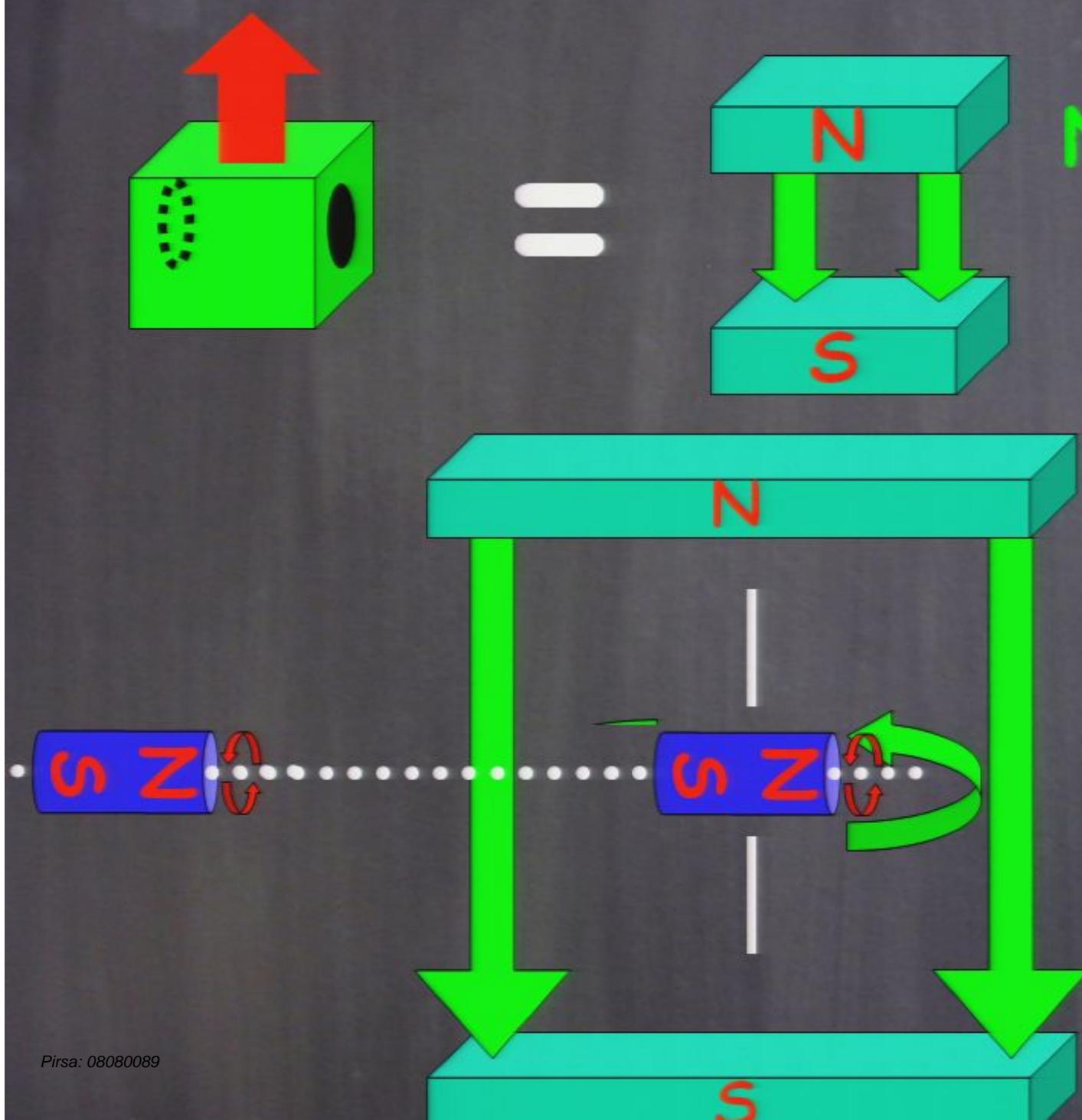
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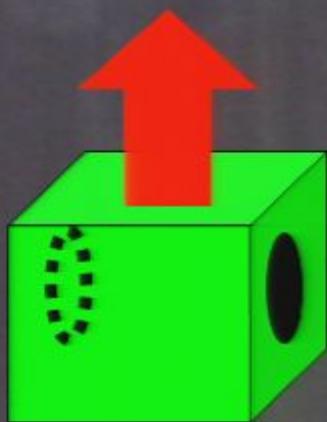


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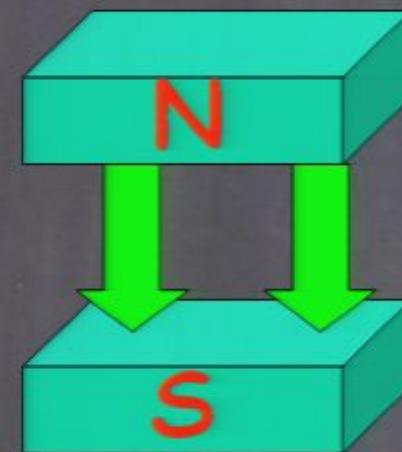


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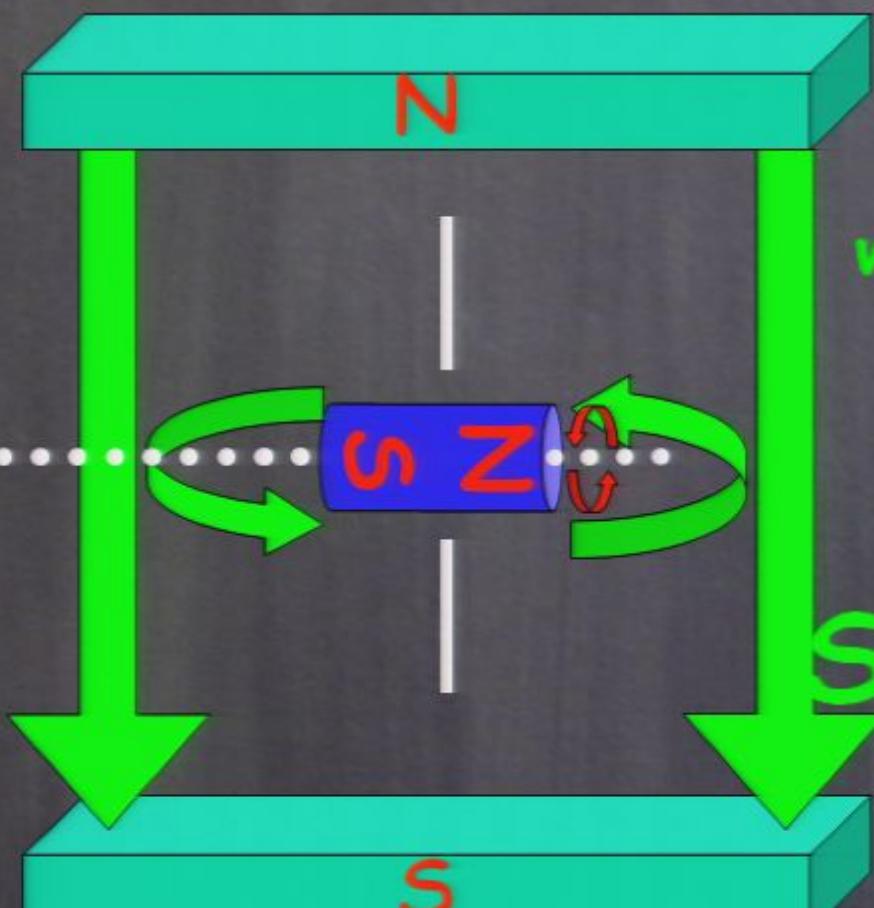


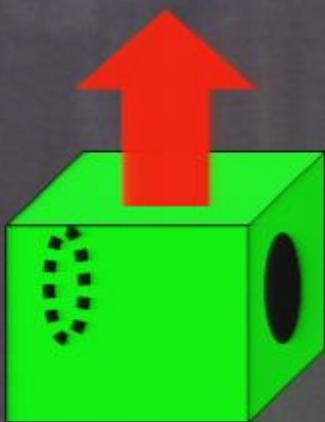


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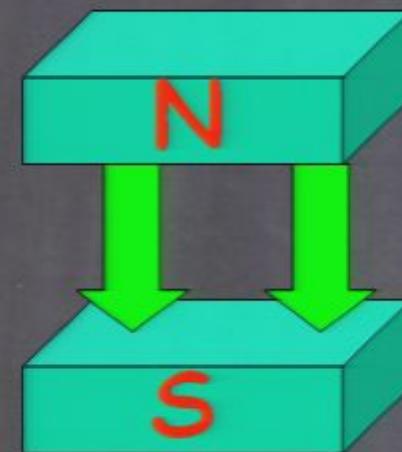


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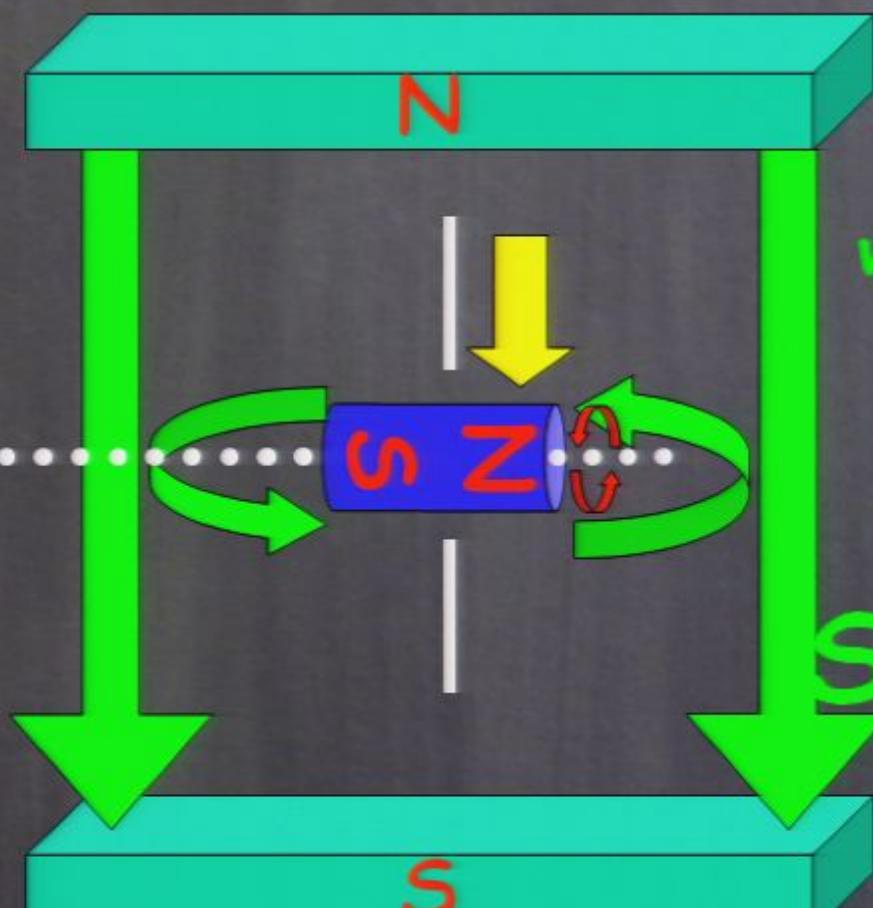


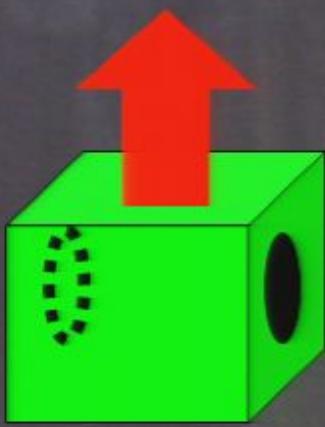


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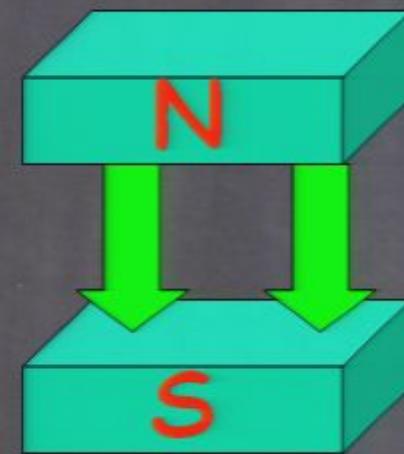


## Nonuniform Magnetic Field





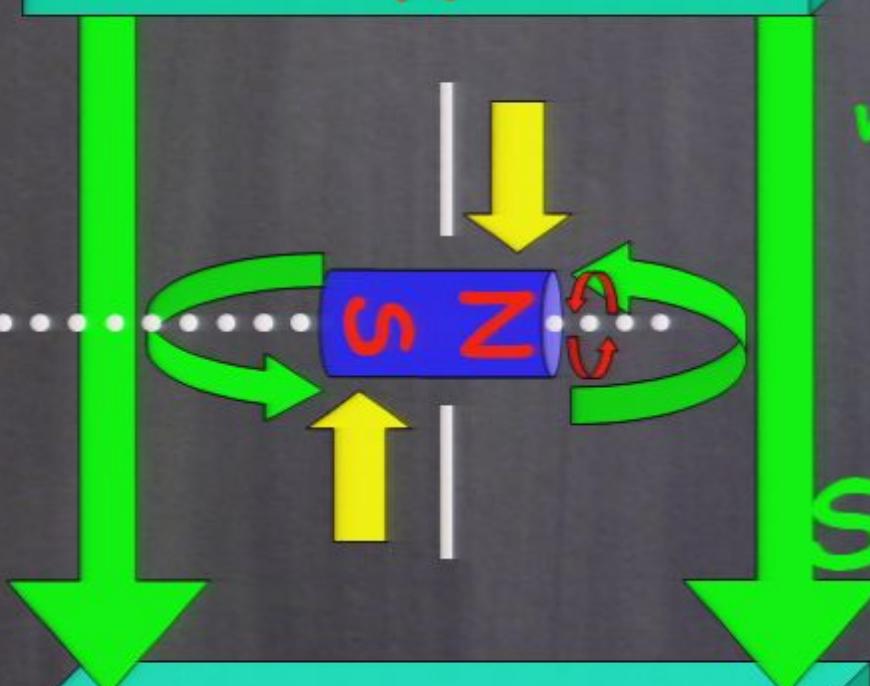
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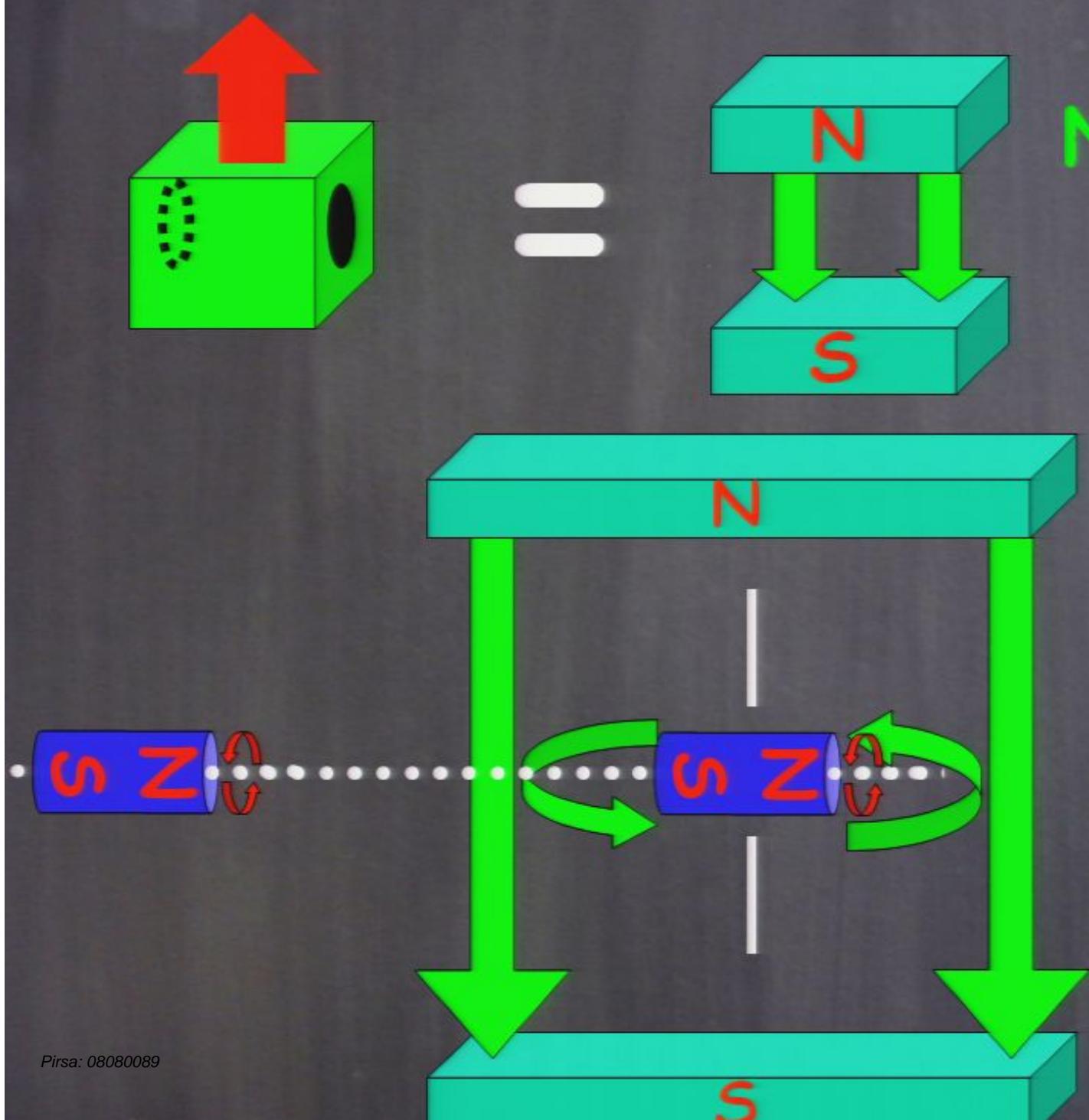
## Nonuniform Magnetic Field



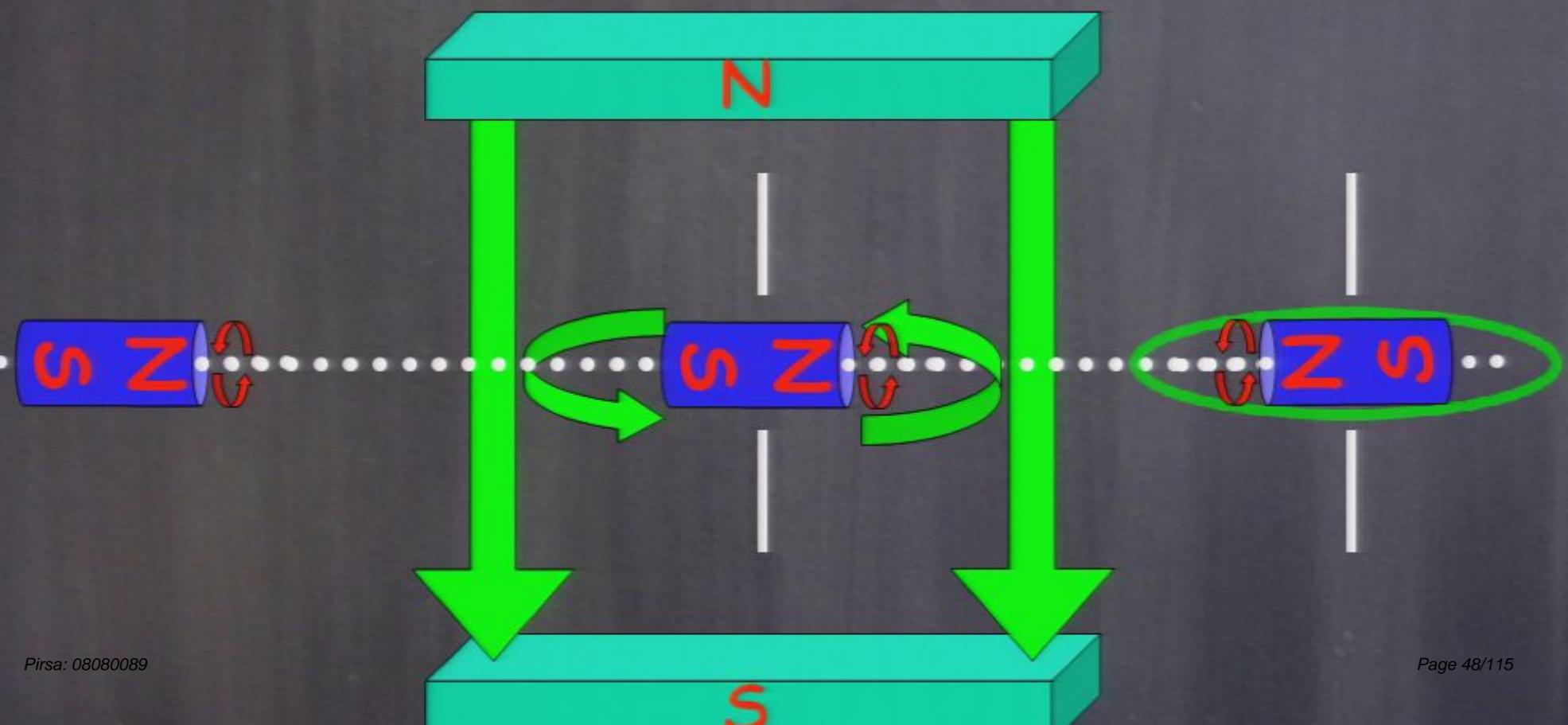
weaker

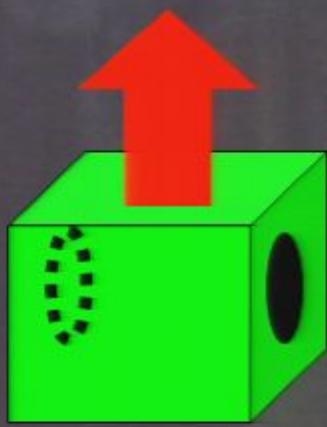


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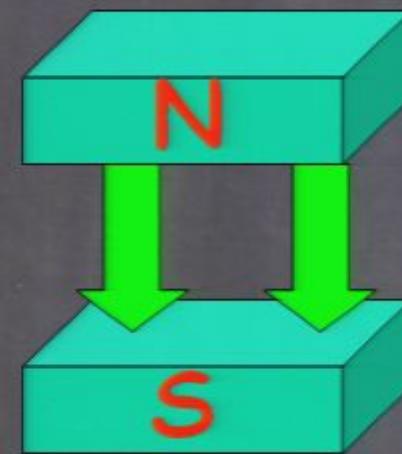


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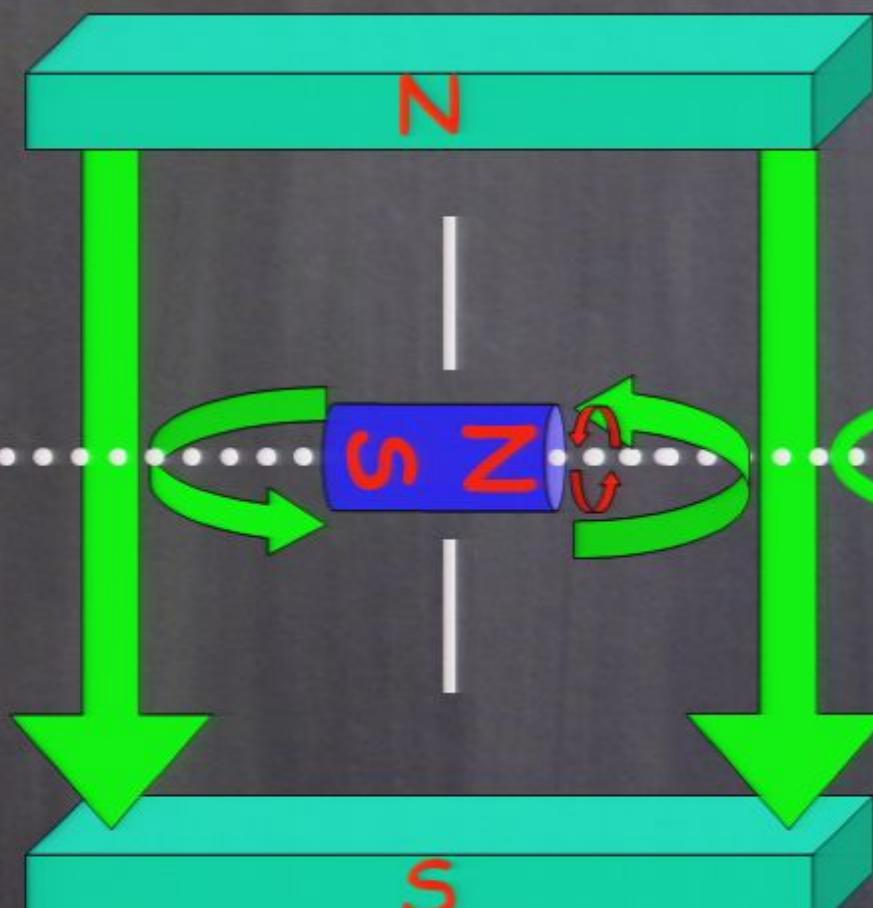




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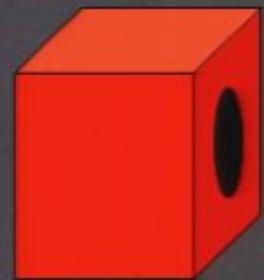
## Nonuniform Magnetic Field



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# Experiment #1

# Experiment #1



# Experiment #1



**Random Spin  
Directions**

# Experiment #1



**Random Spin  
Directions**

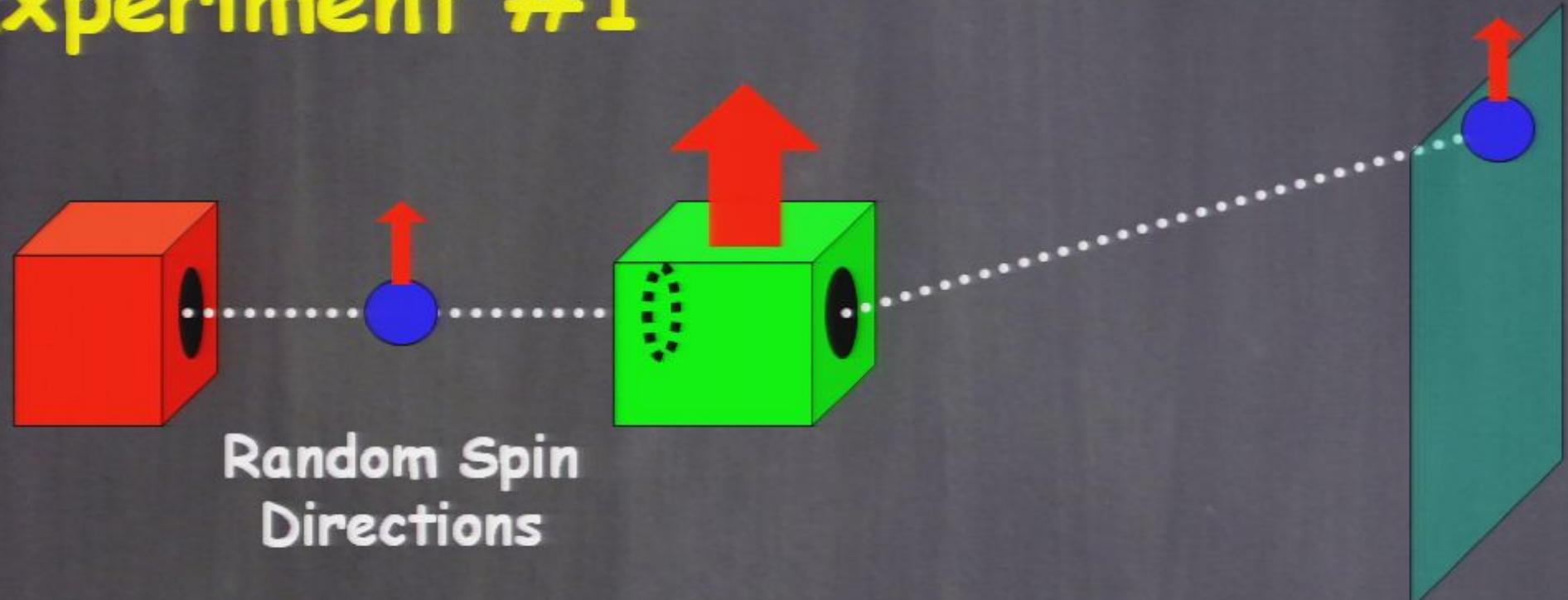
# Experiment #1



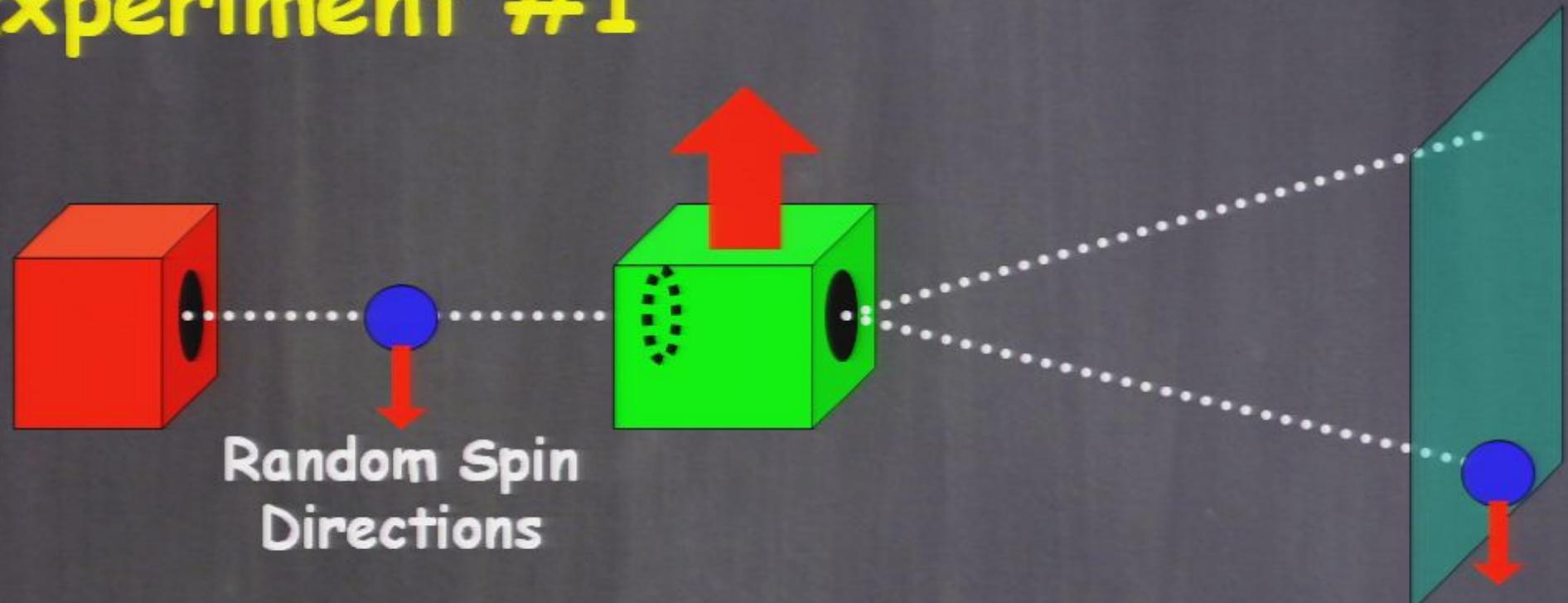
**Random Spin  
Directions**



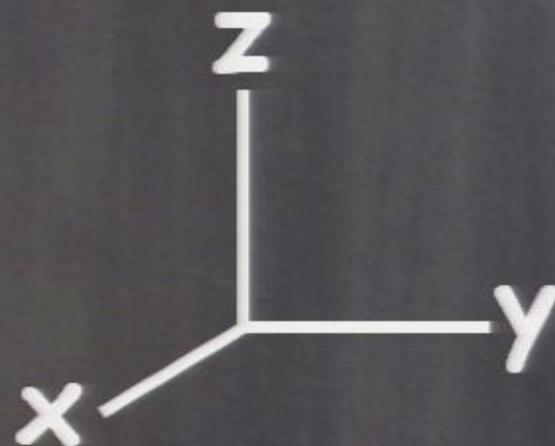
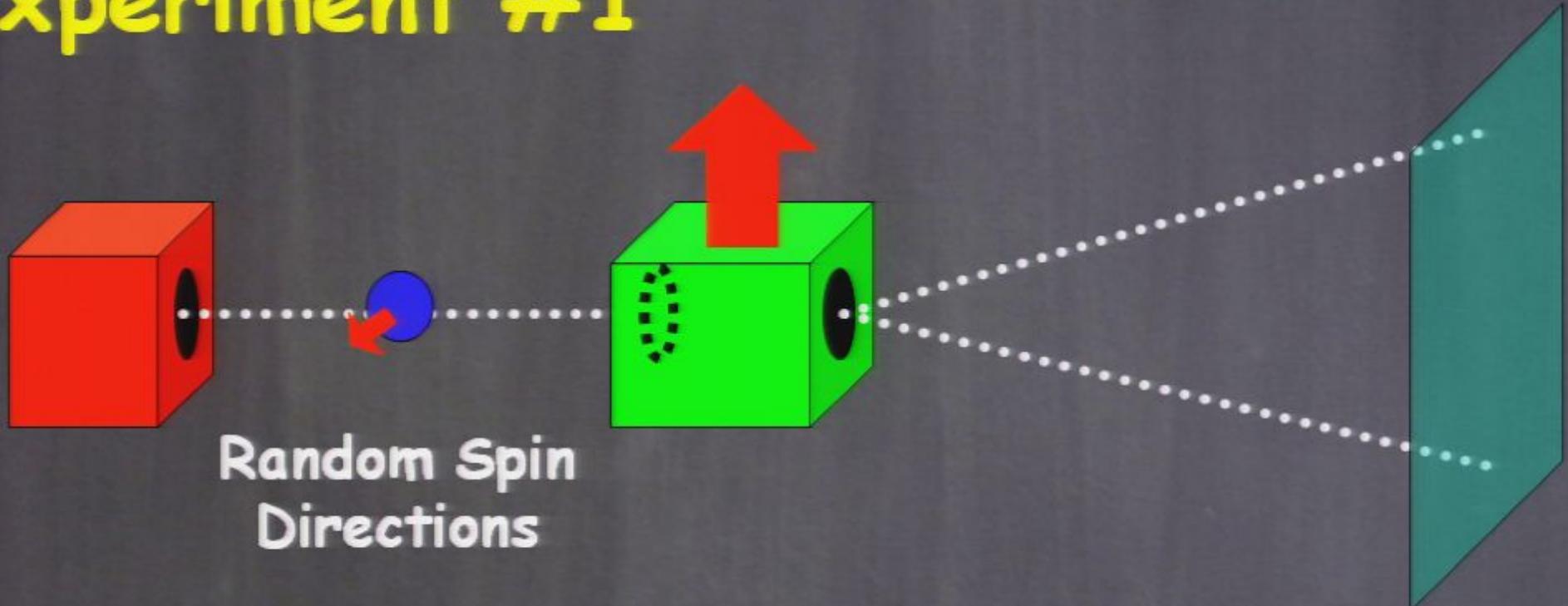
# Experiment #1



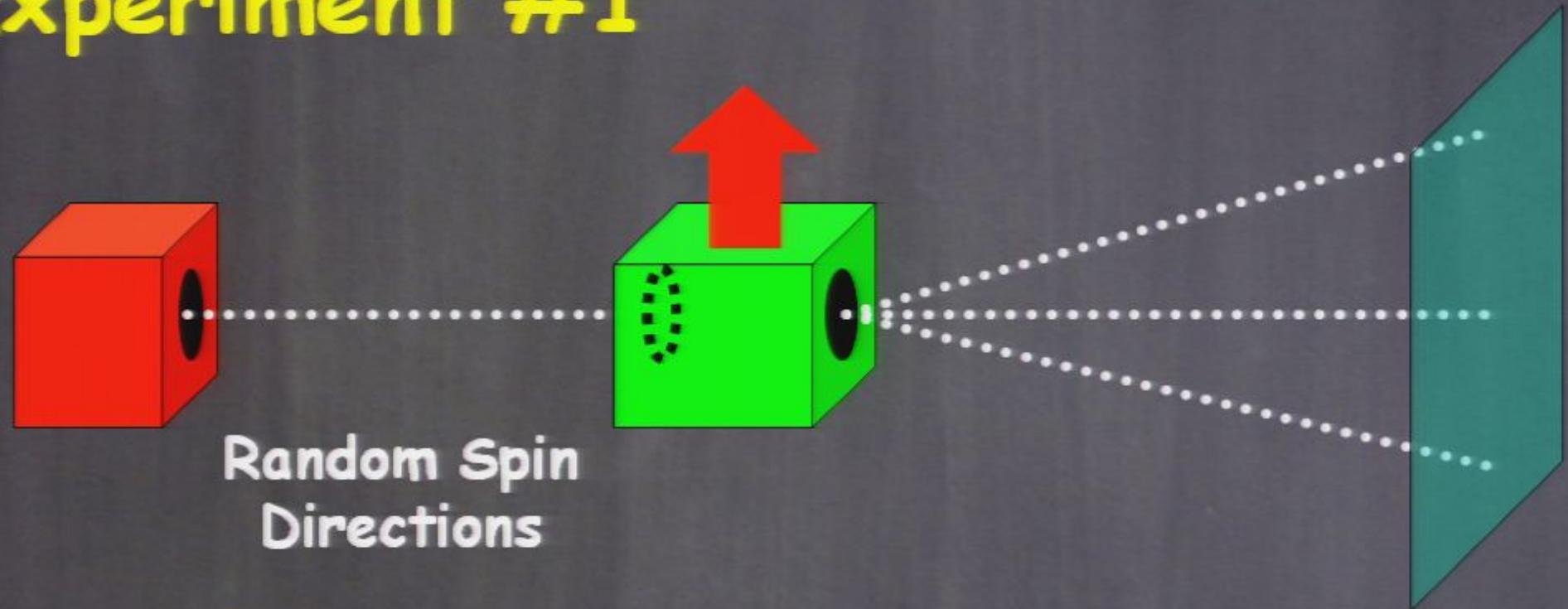
# Experiment #1



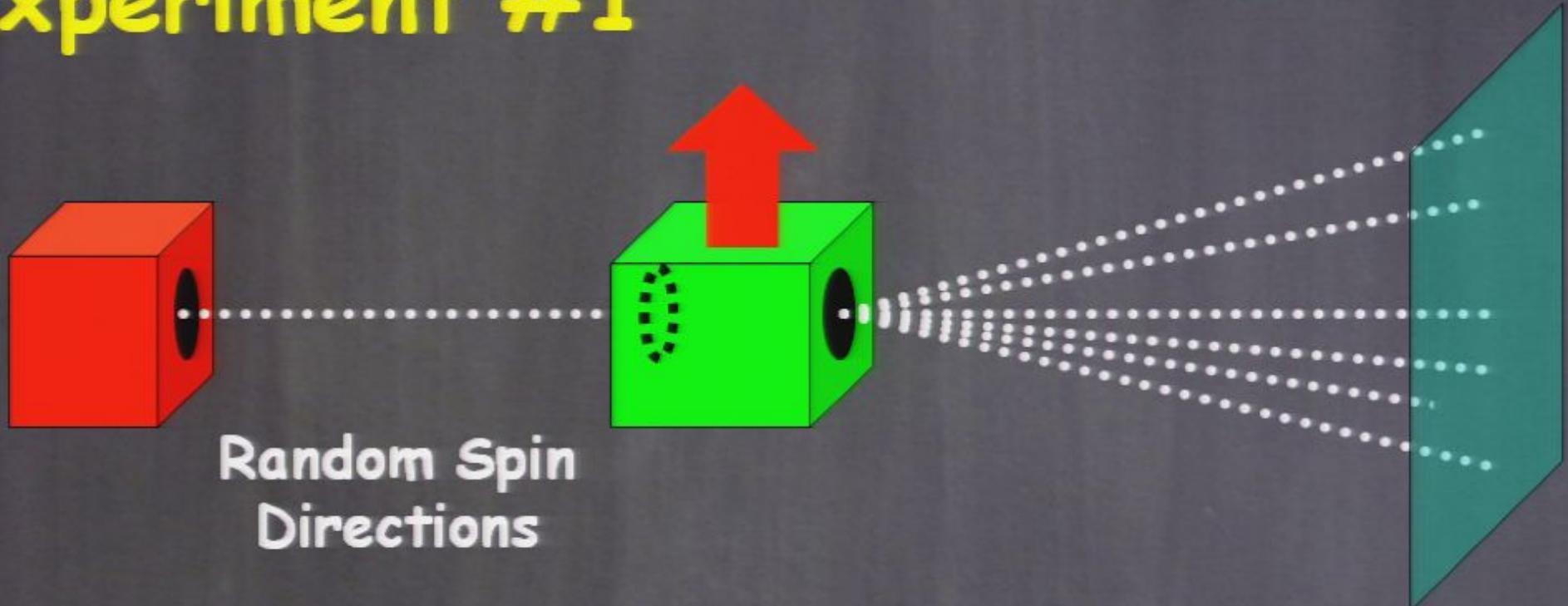
# Experiment #1



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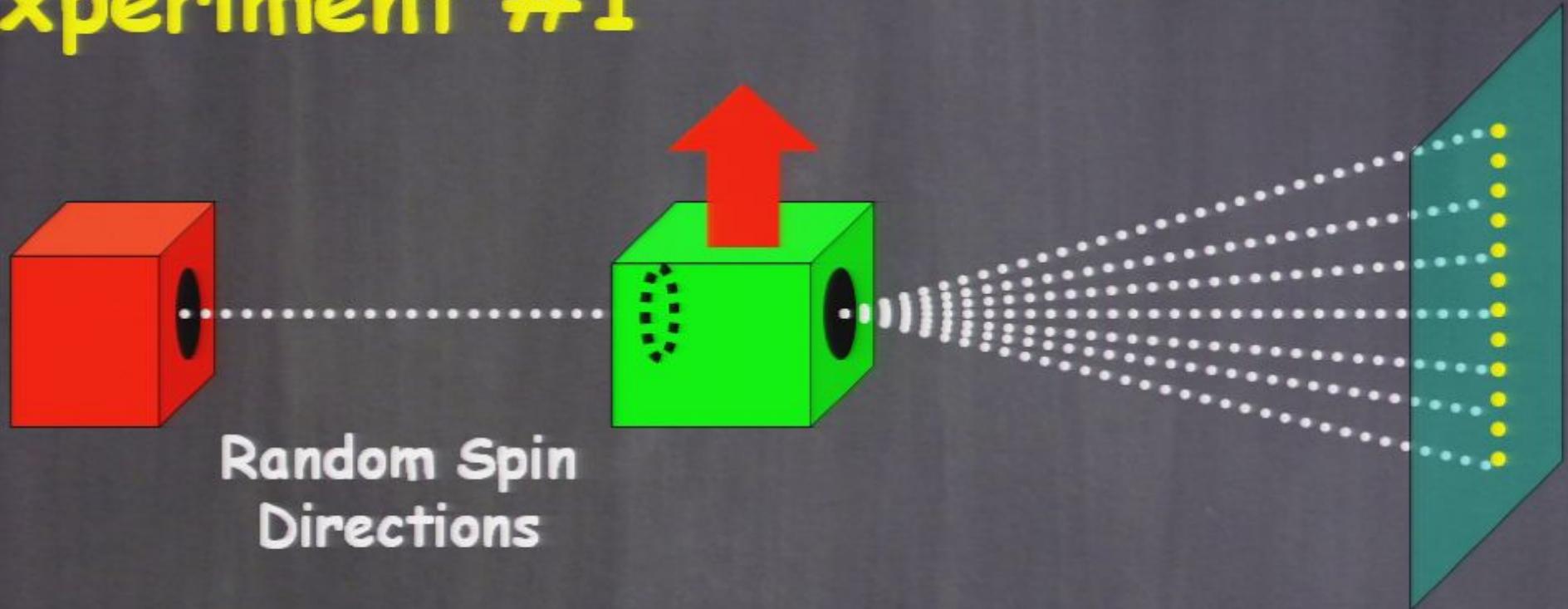


# Experiment #1



**Random Spin  
Directions**

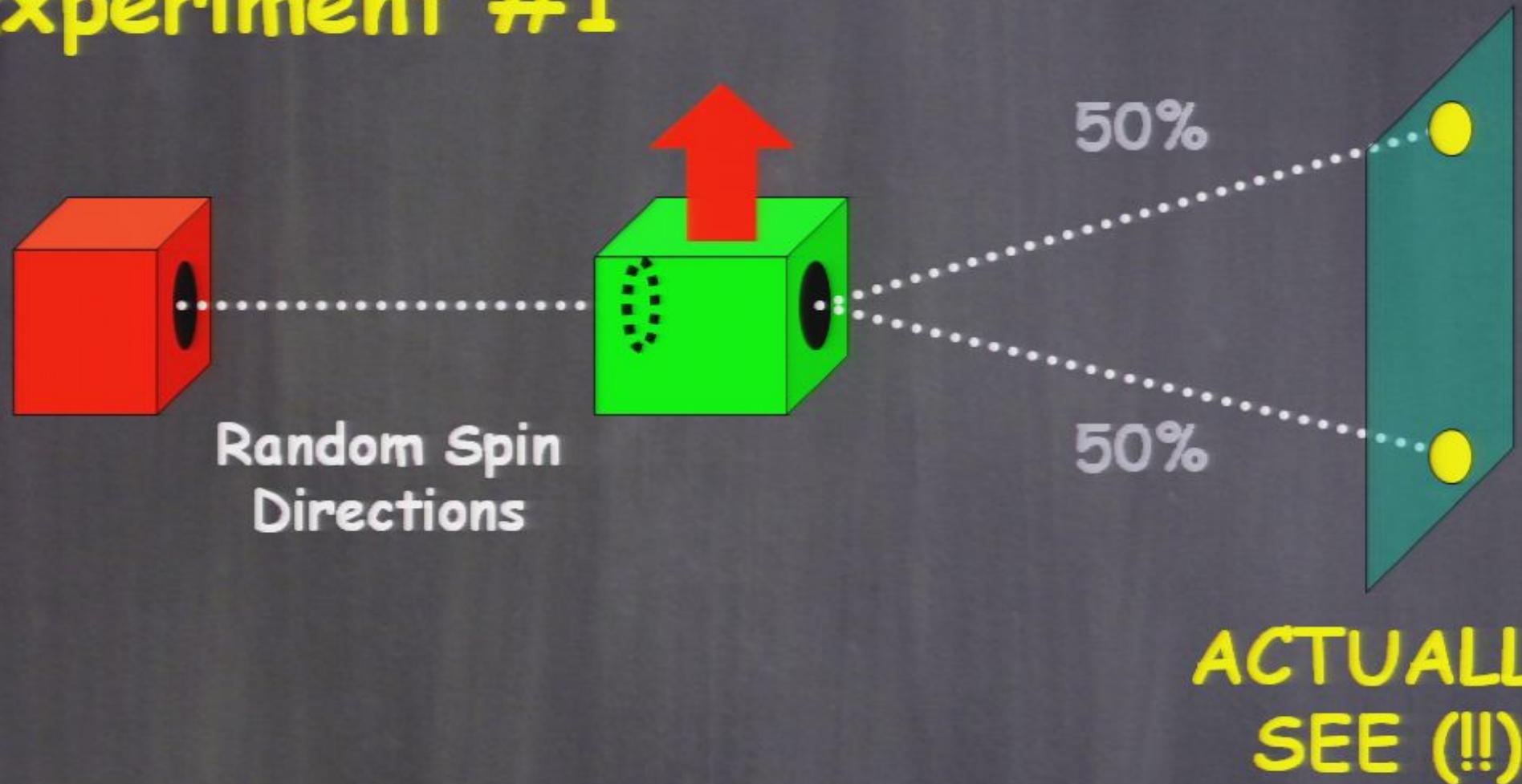
# Experiment #1



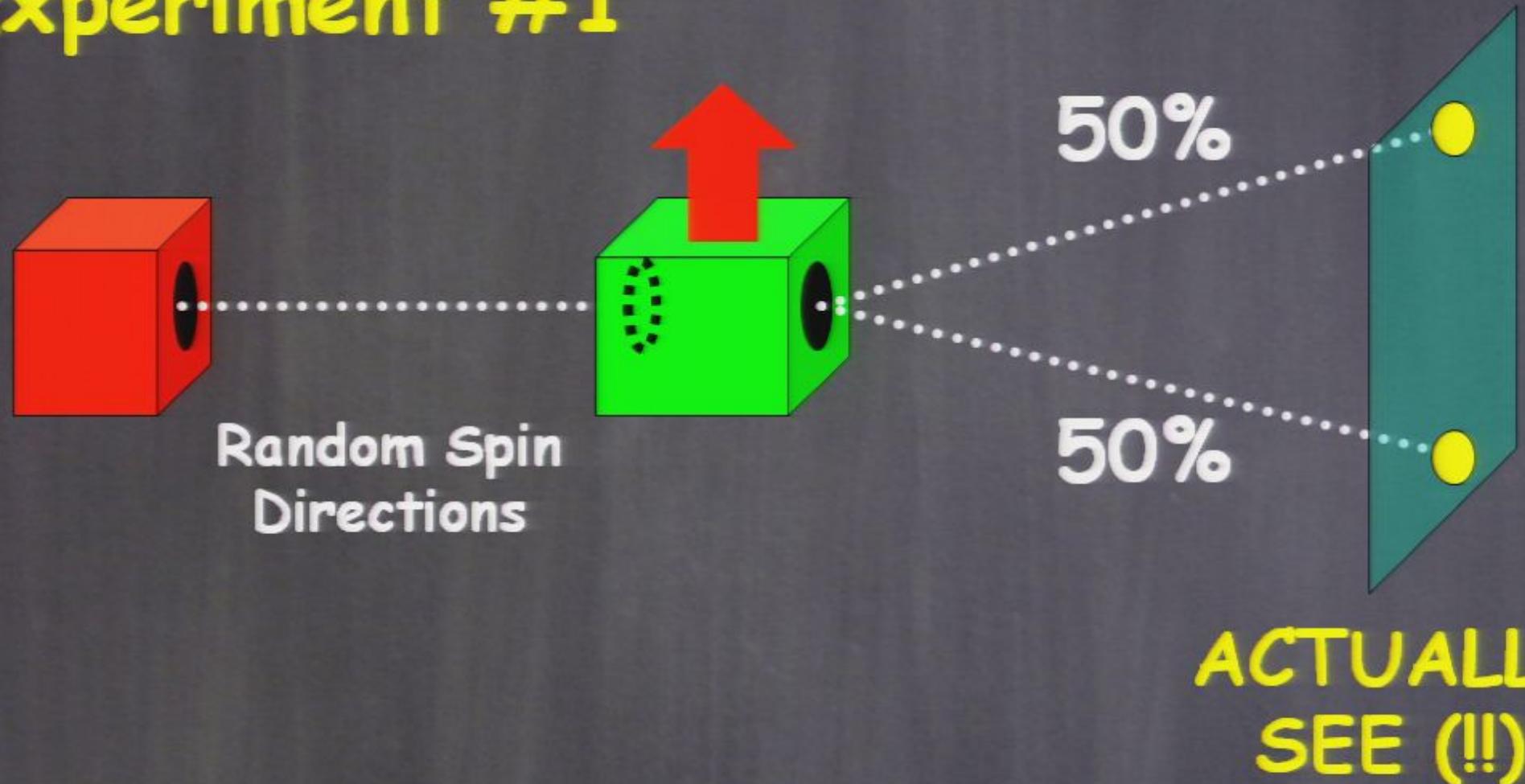
**Random Spin  
Directions**

**EXPECT  
TO SEE**

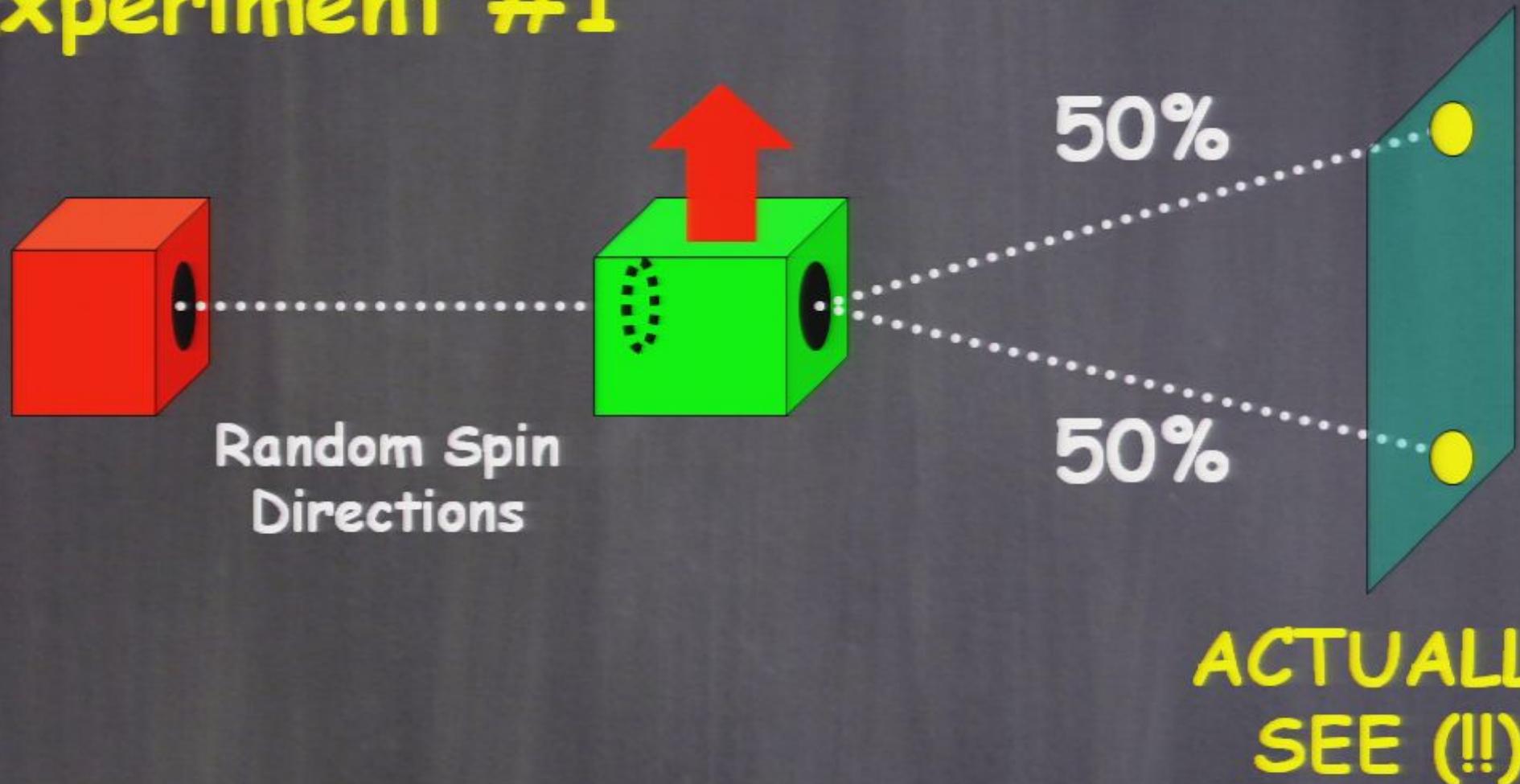
# Experiment #1



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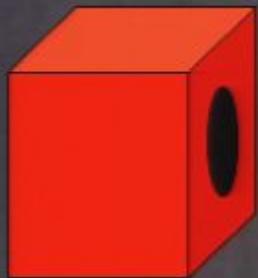
# Experiment #1



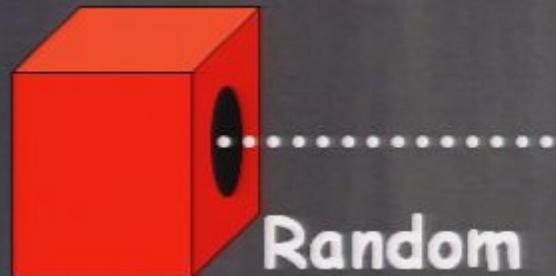
This result has no “classical” or “commonsense” explanation

# Experiment #2

# Experiment #2

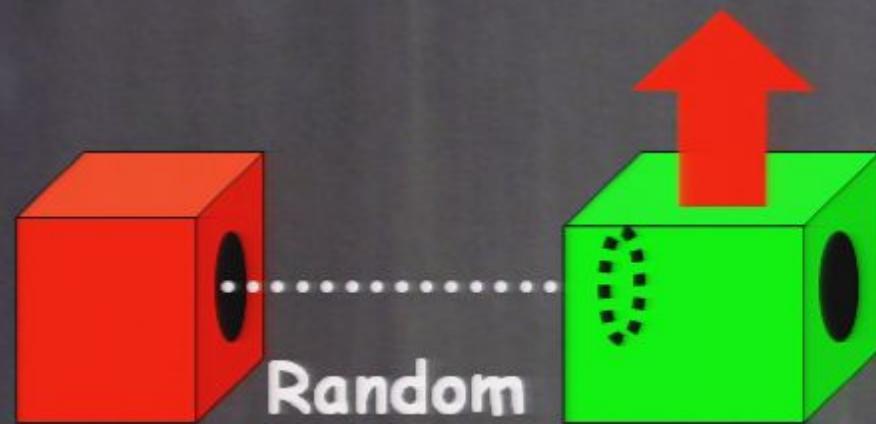


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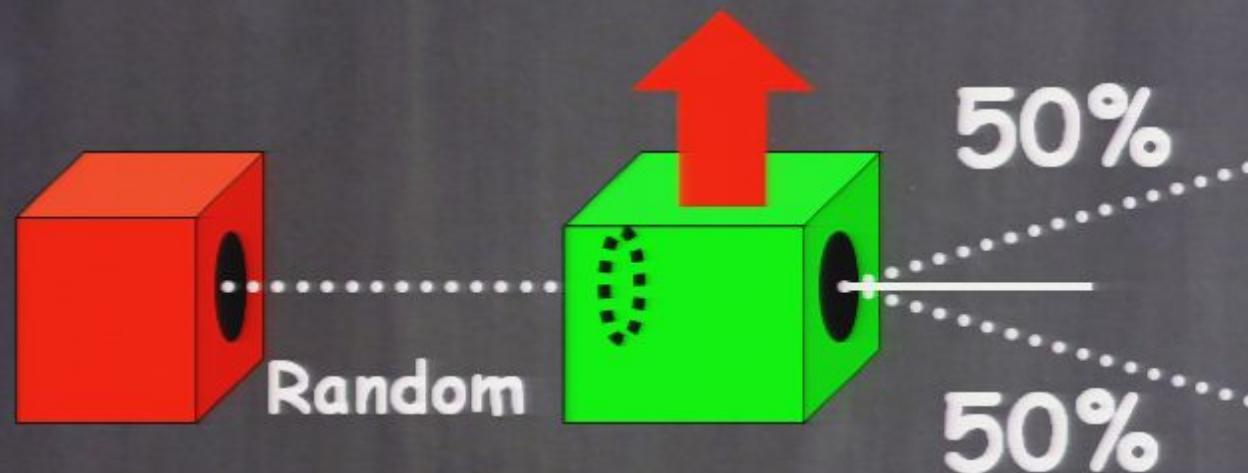


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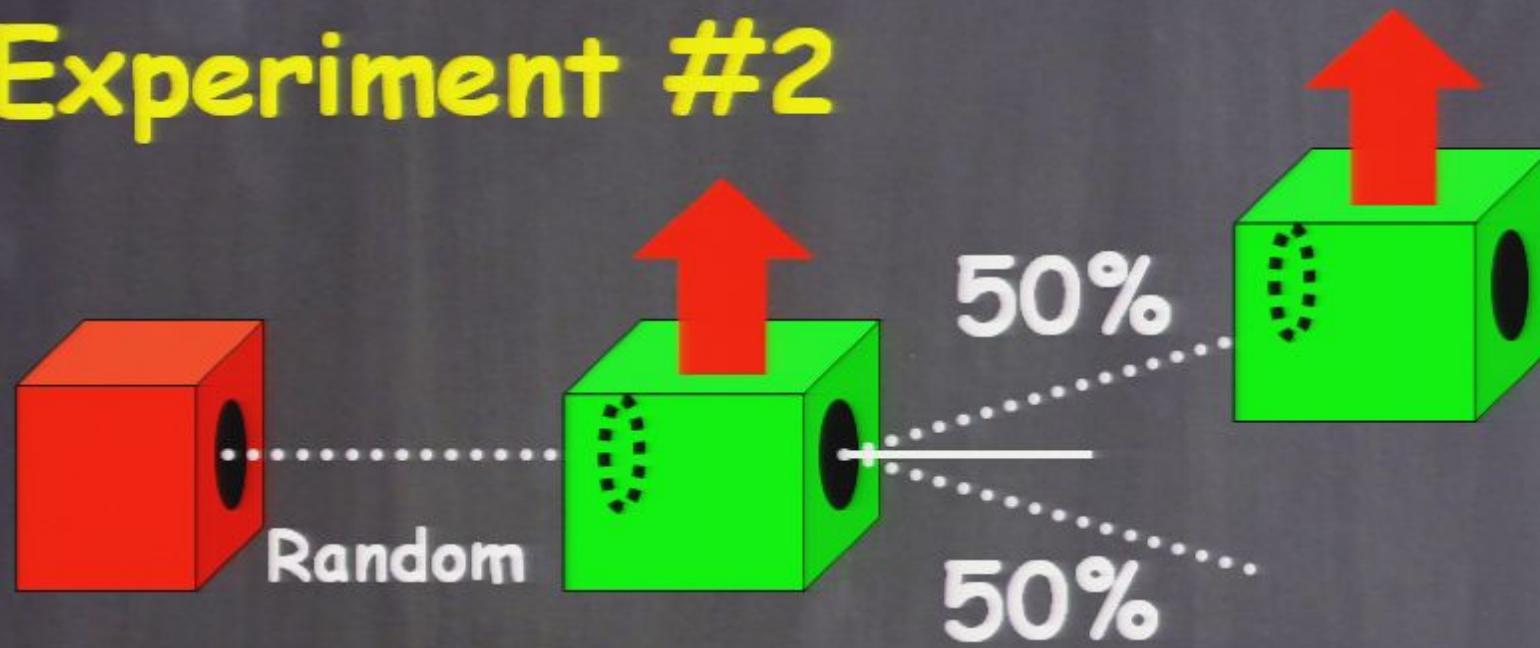
# Experiment #2



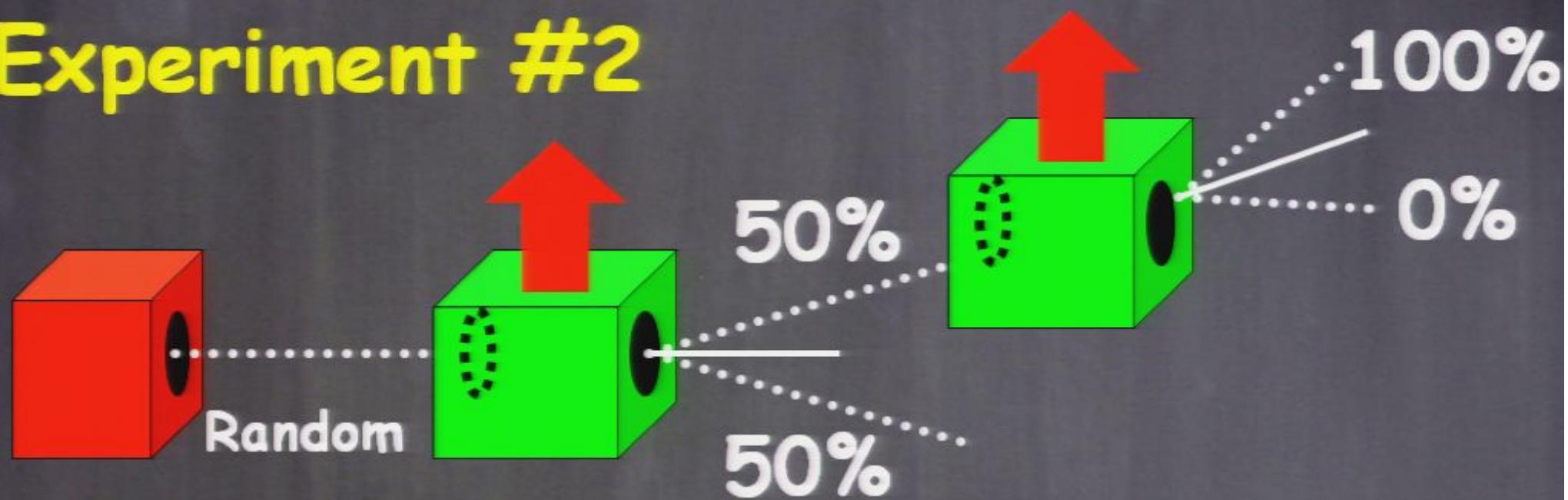
## Experiment #2



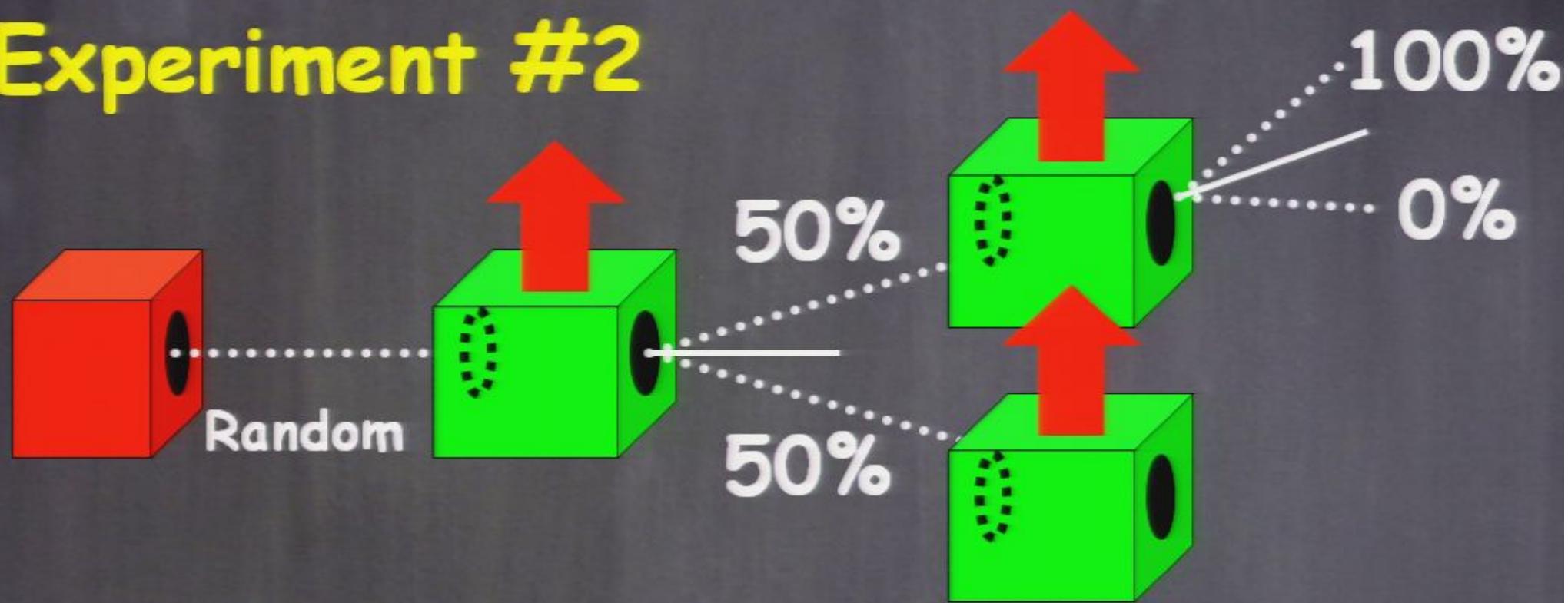
## Experiment #2



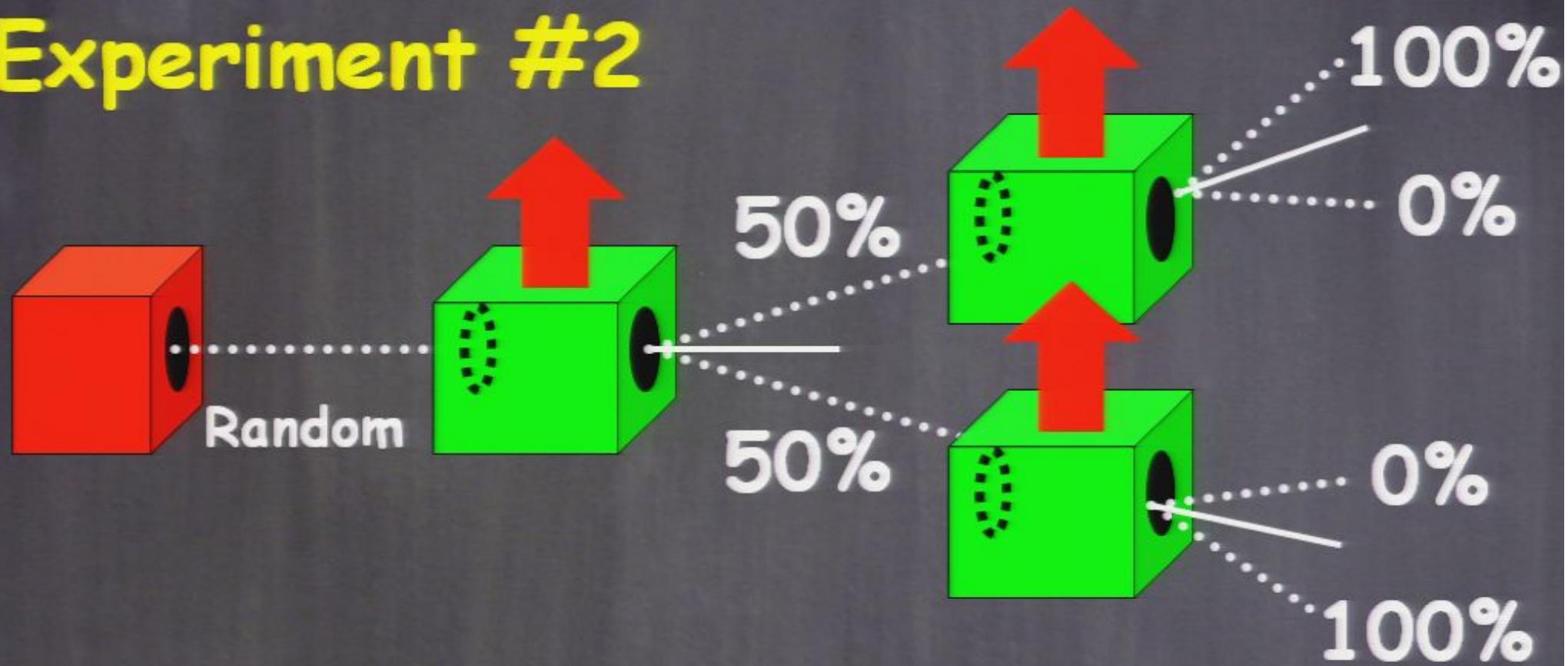
## Experiment #2



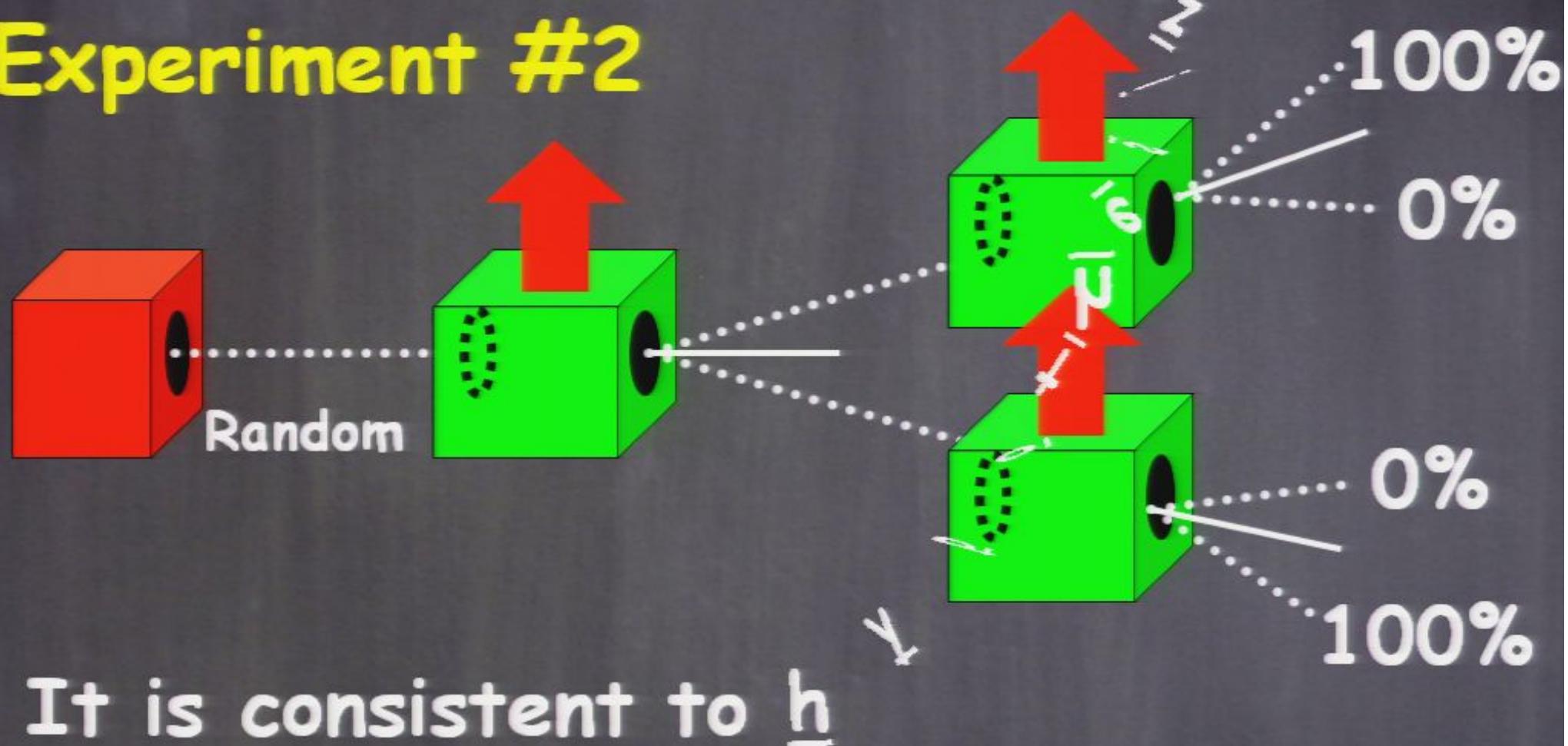
## Experiment #2



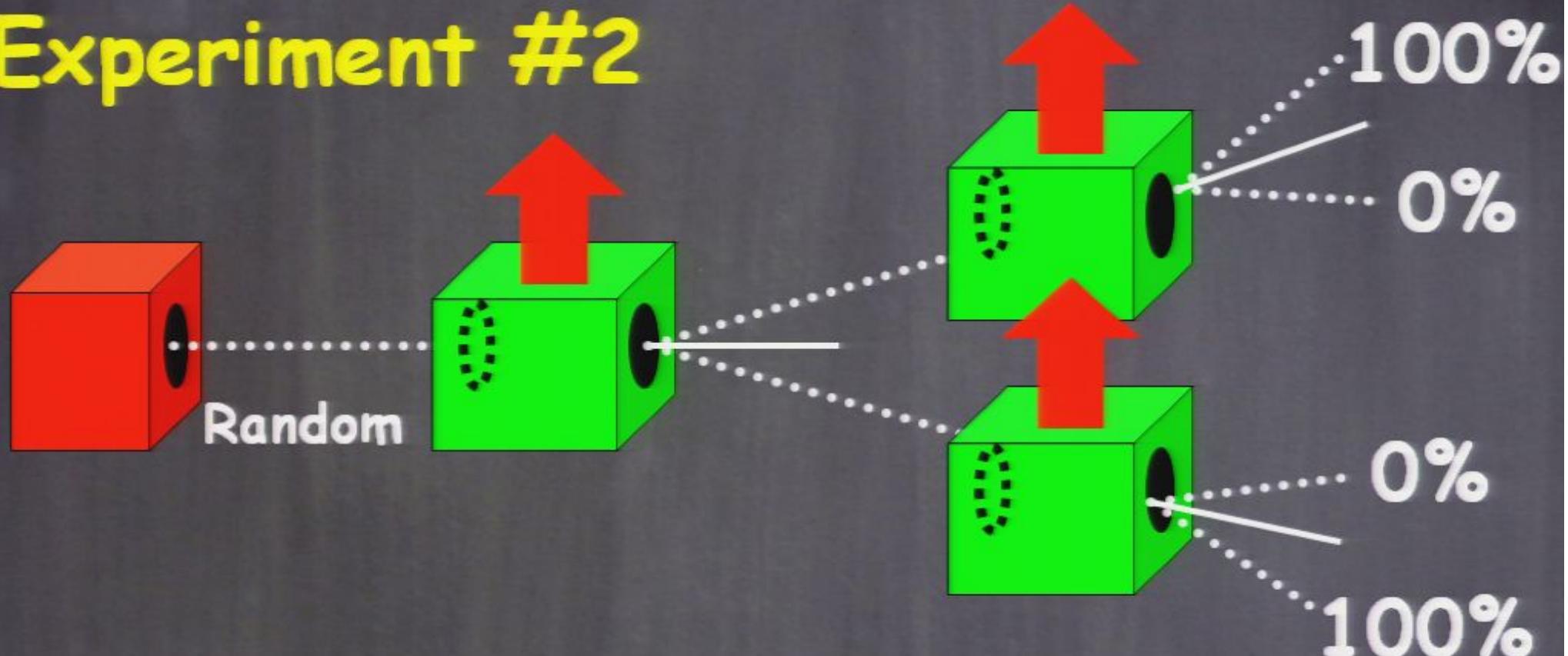
## Experiment #2



## Experiment #2

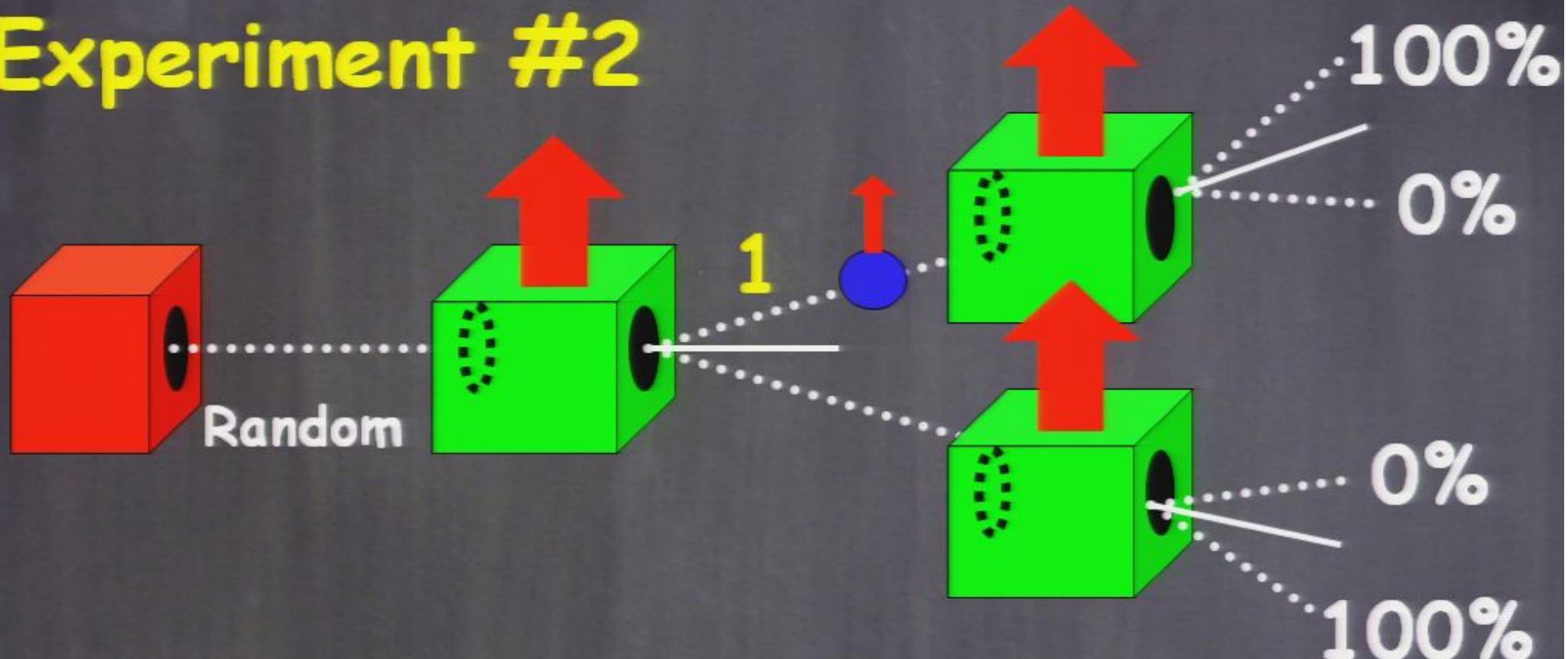


## Experiment #2



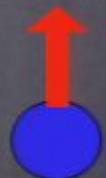
It is consistent to hypothesize:

## Experiment #2

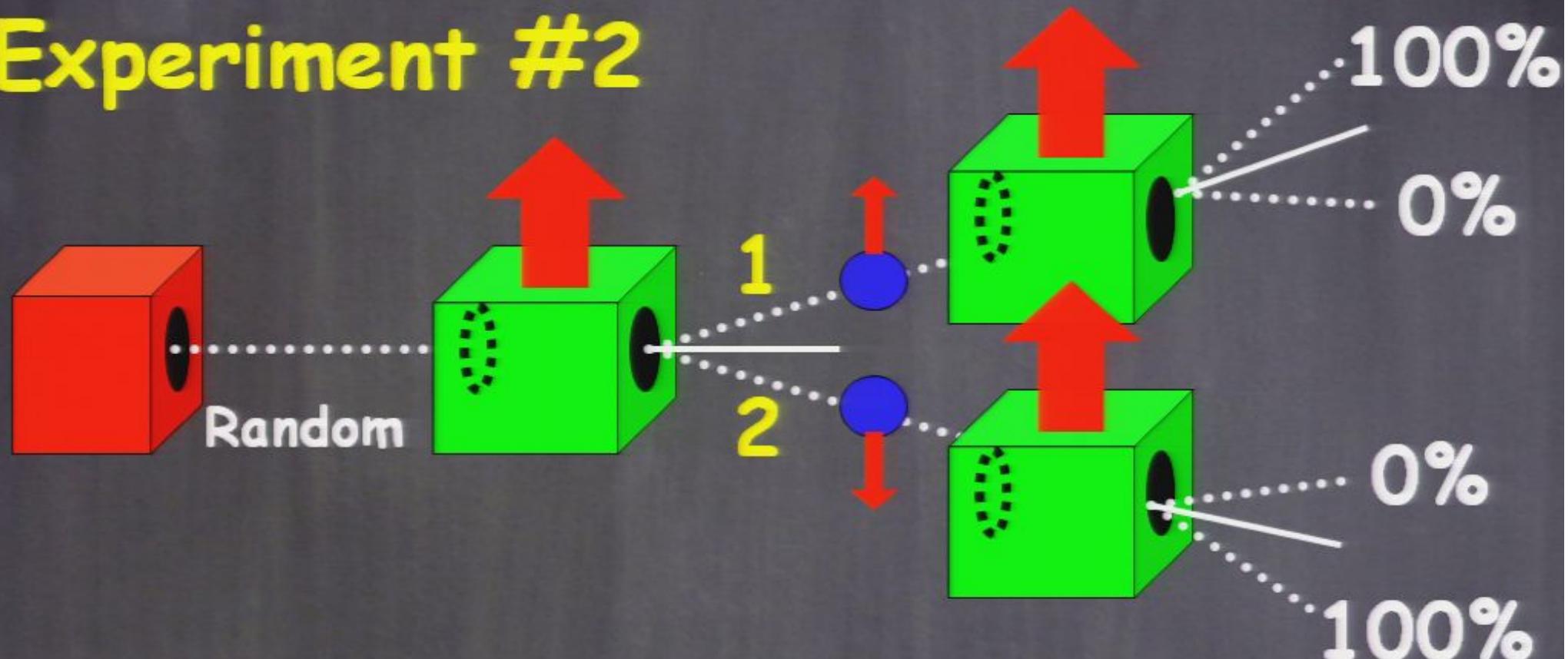


It is consistent to hypothesize:

**Beam 1 atoms are all “spin up”:**

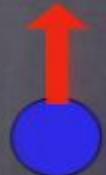


## Experiment #2



It is consistent to hypothesize:

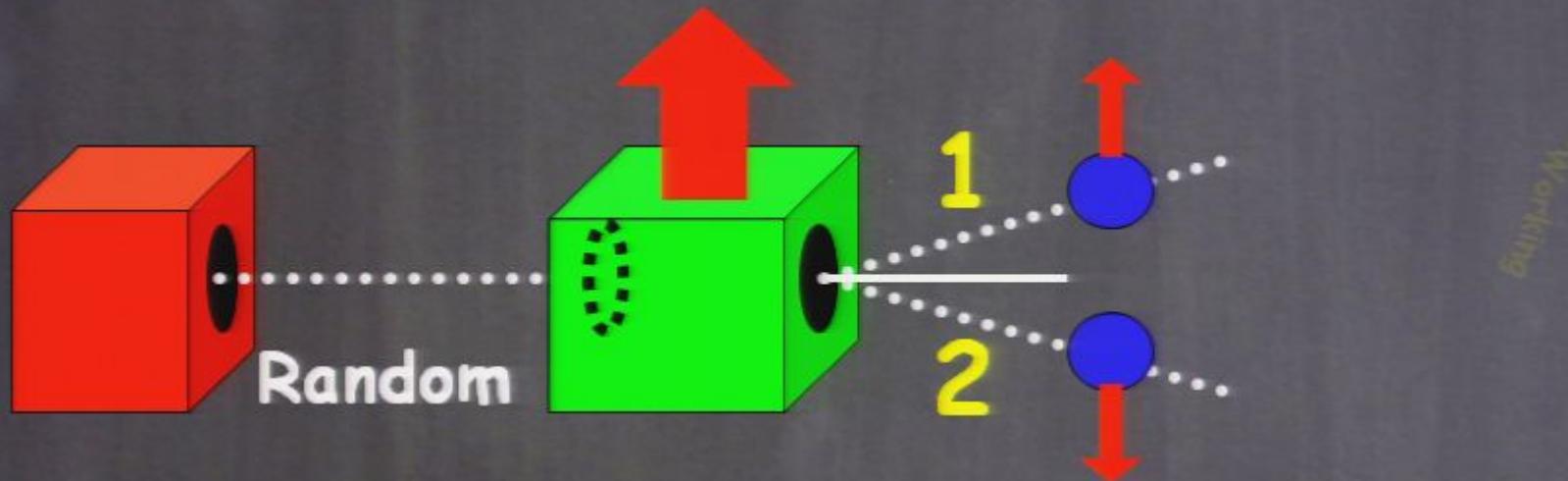
**Beam 1** atoms are all “spin up”:



**Beam 2** atoms are all “spin down”:

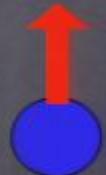


## Experiment #2



It is consistent to hypothesize:

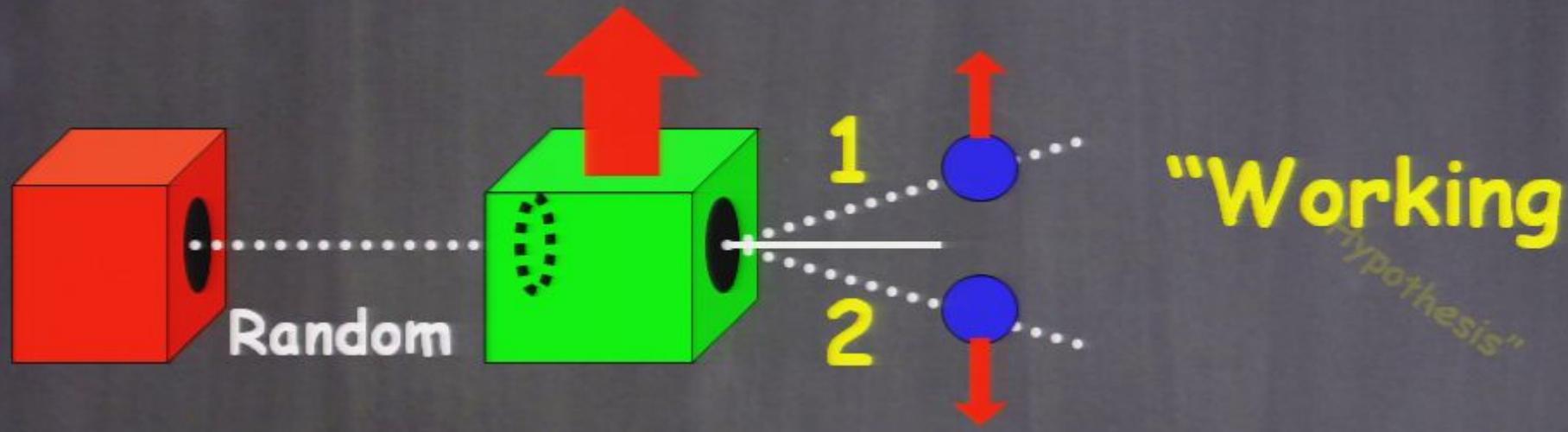
**Beam 1** atoms are all “spin up”:



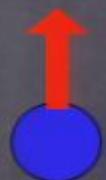
**Beam 2** atoms are all “spin down”:



## Experiment #2



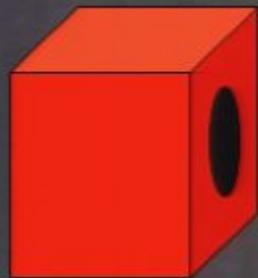
It is consistent to hypothesize:

**Beam 1** atoms are all "spin up": 

**Beam 2** atoms are all "spin down": 

# Experiment #3

# Experiment #3



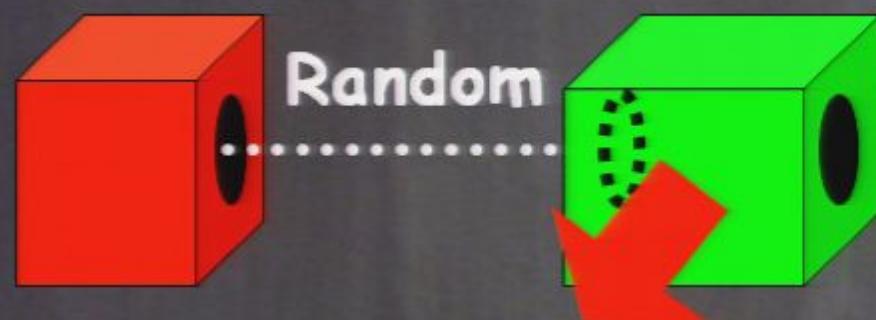
# Experiment #3



# Experiment #3



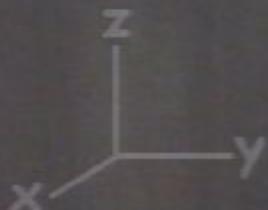
# Experiment #3



# Experiment #3



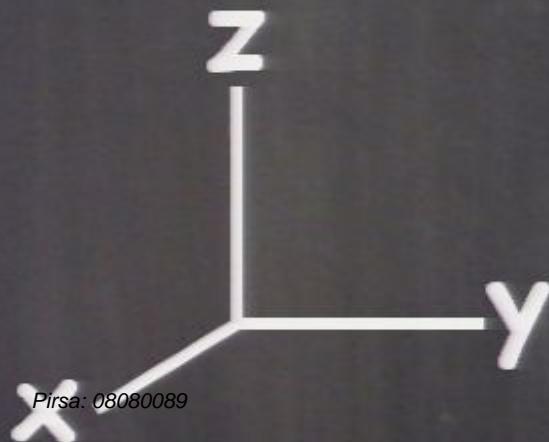
HORIZONTAL



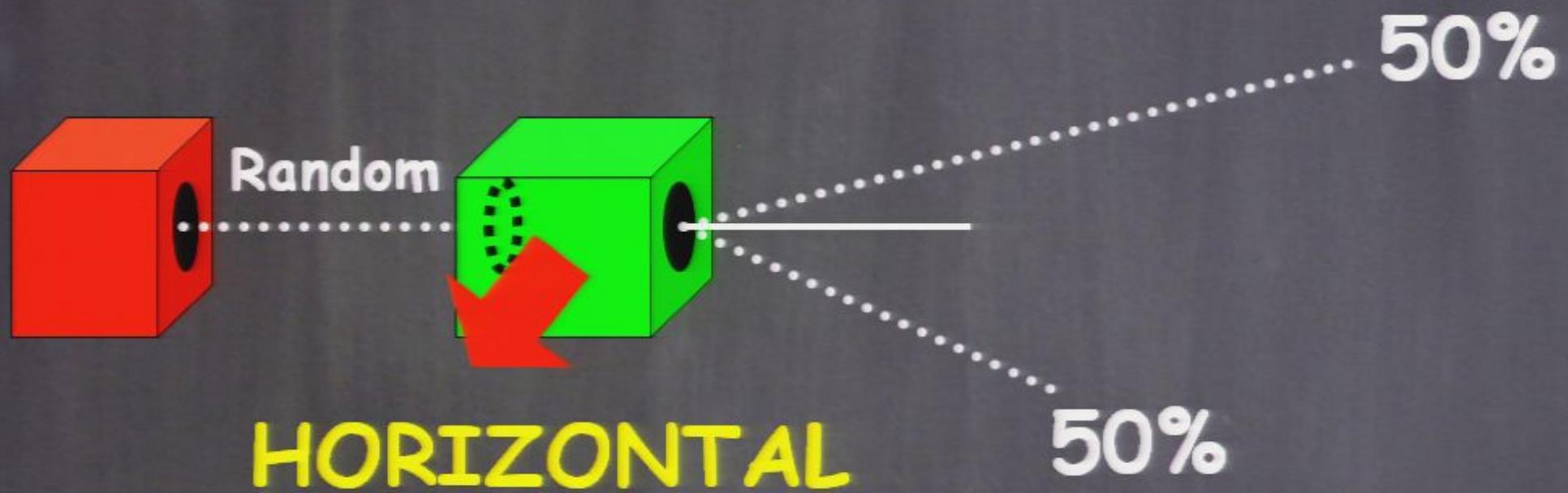
# Experiment #3



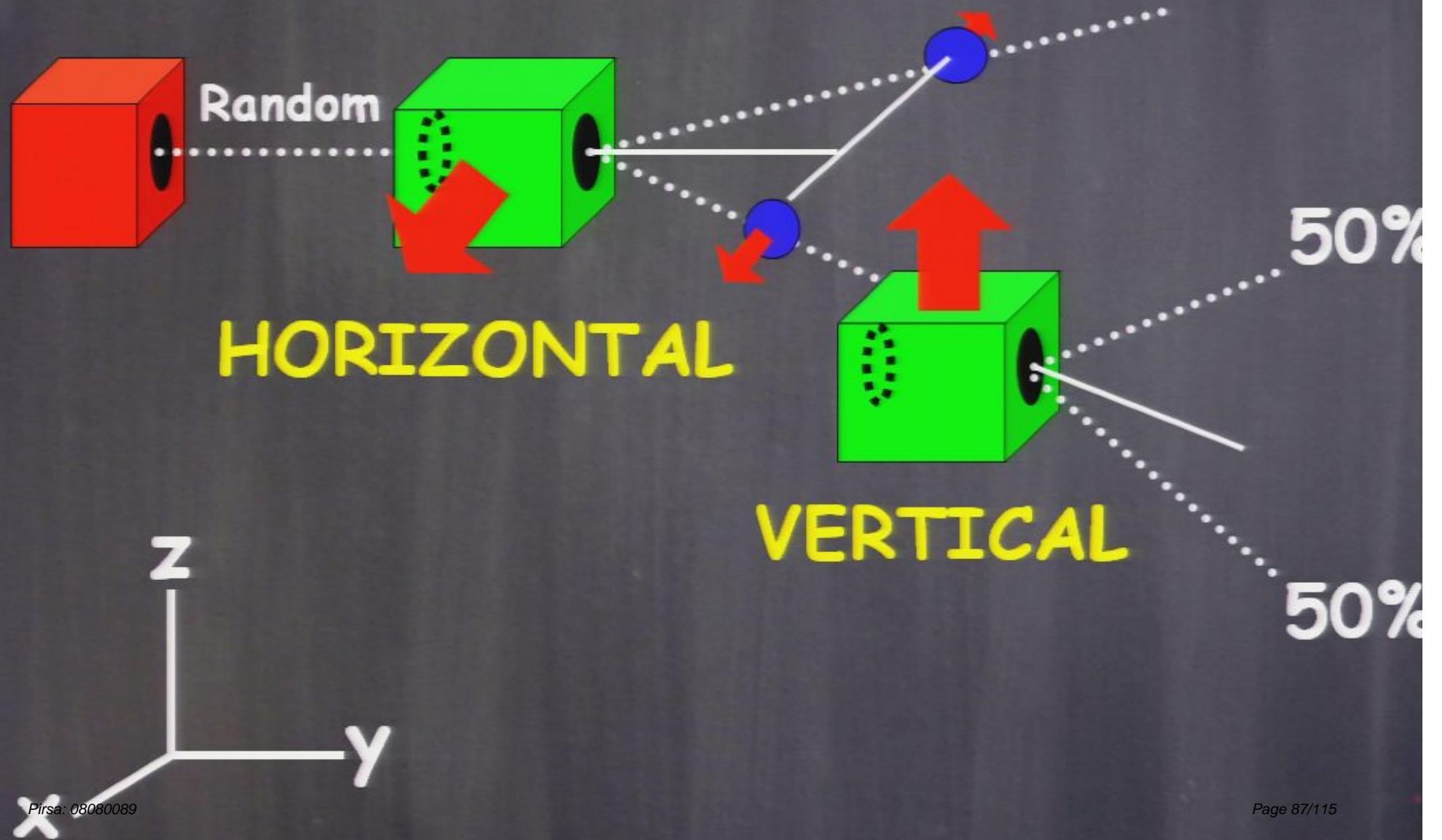
HORIZONTAL



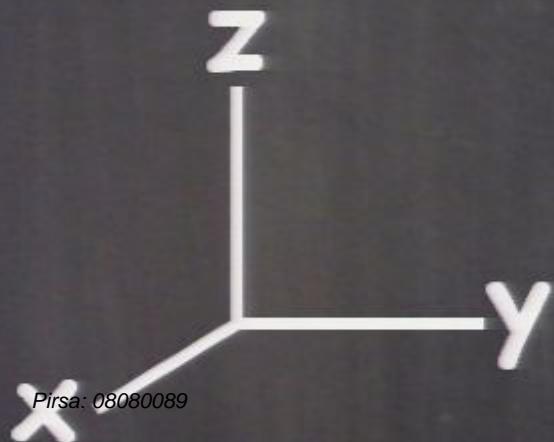
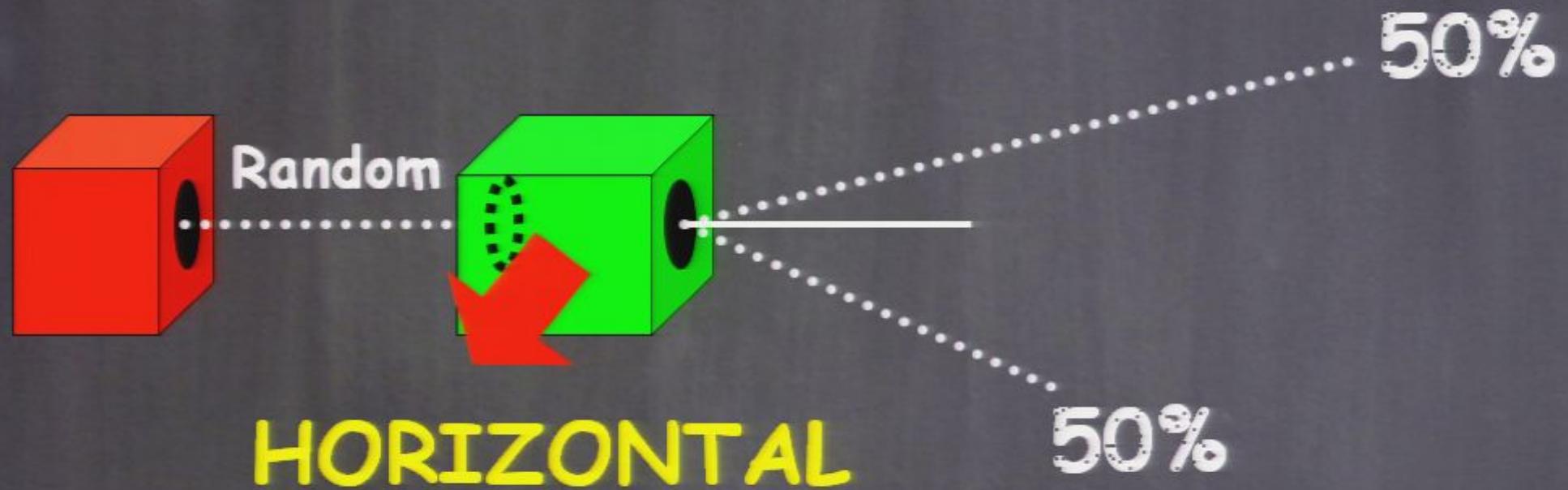
# Experiment #3



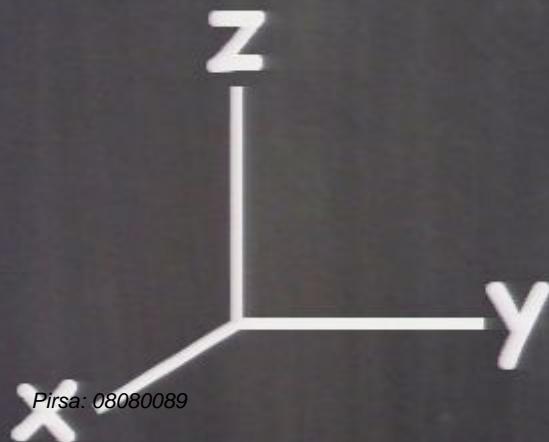
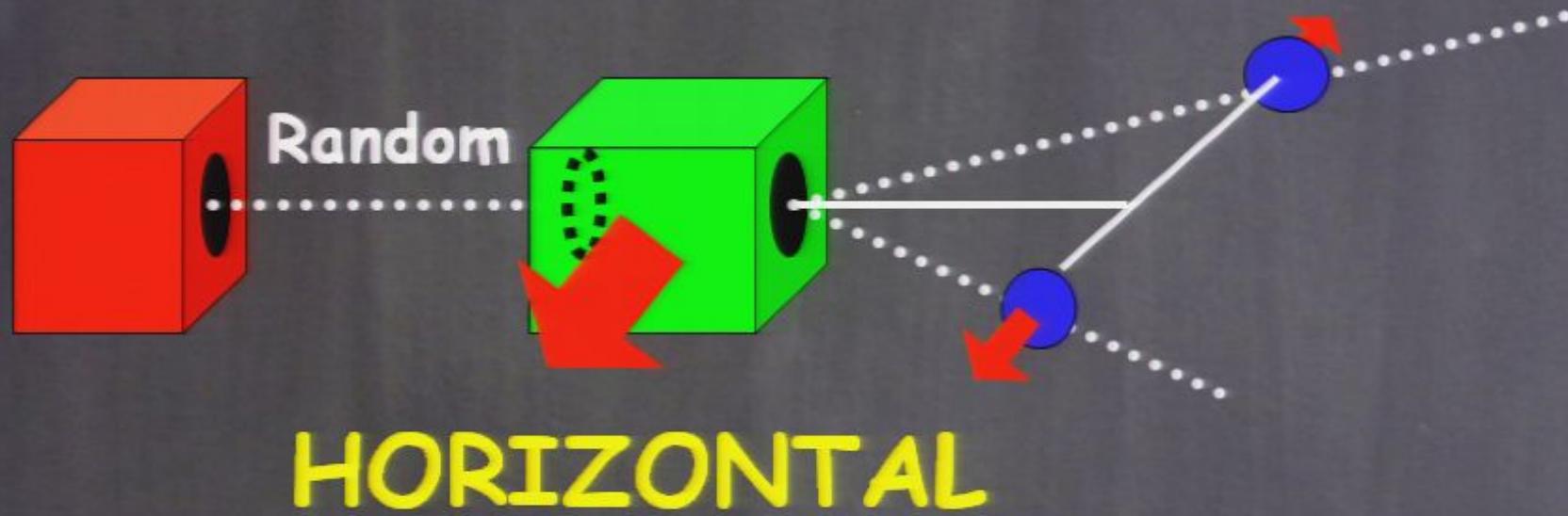
# Experiment #3



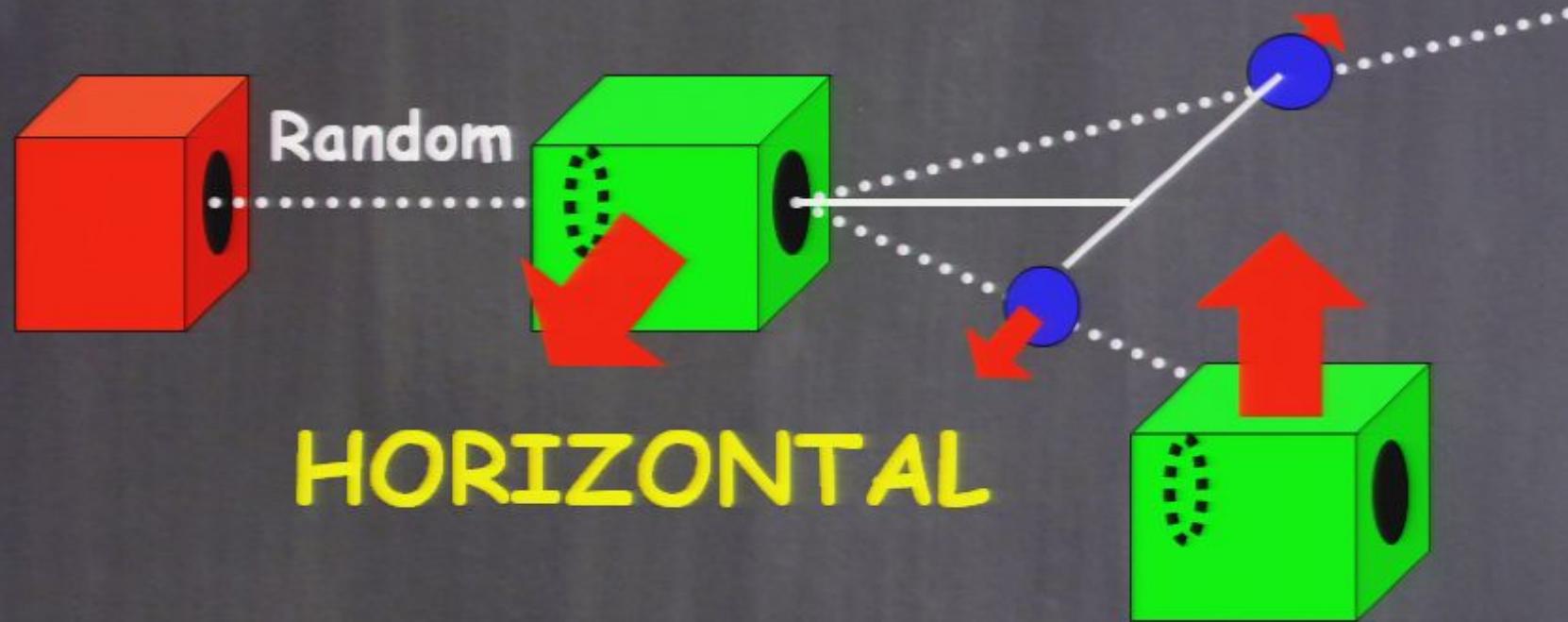
# Experiment #3



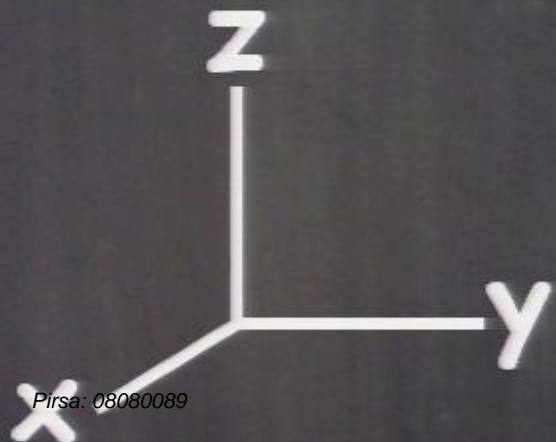
# Experiment #3



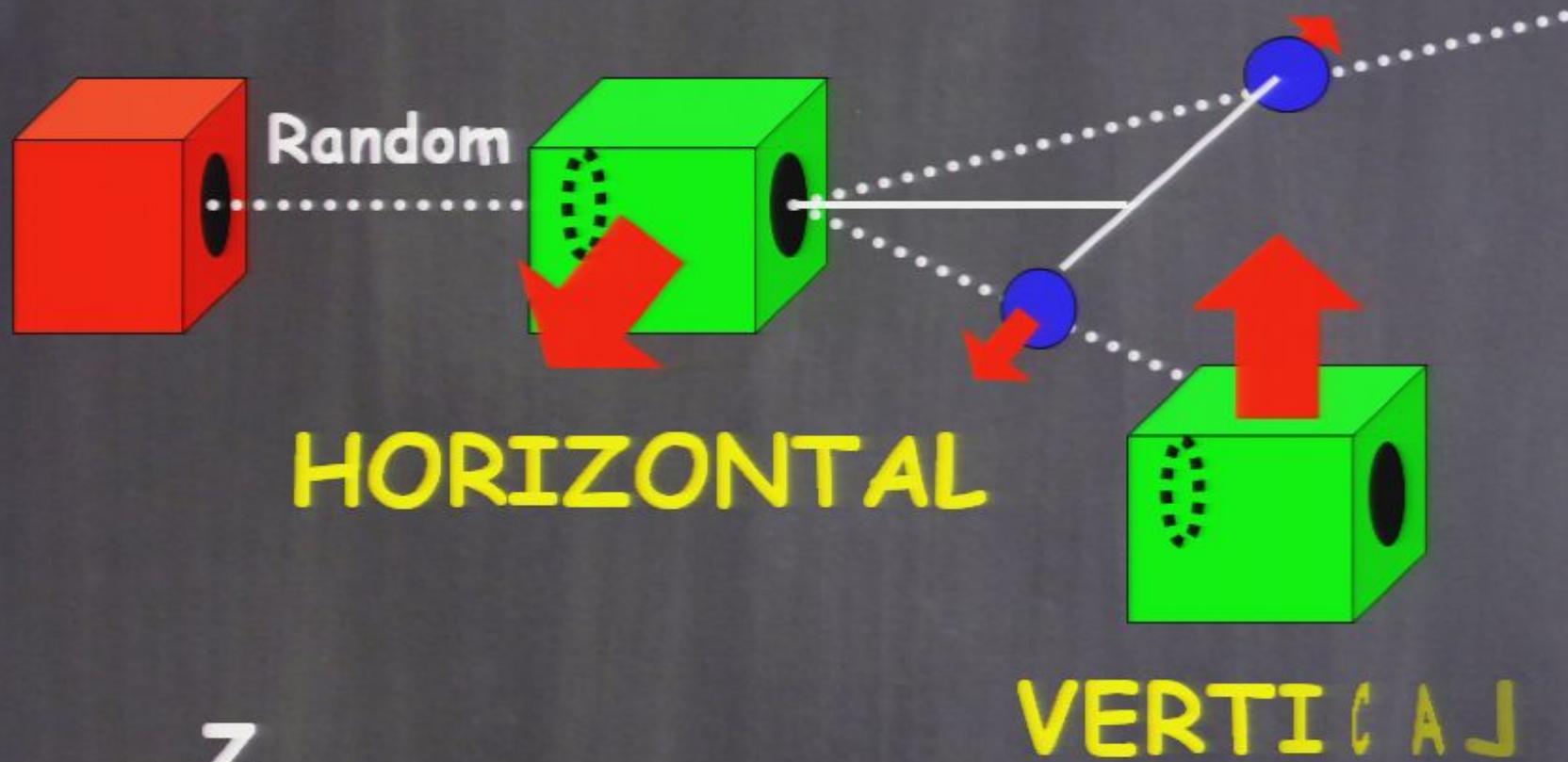
# Experiment #3



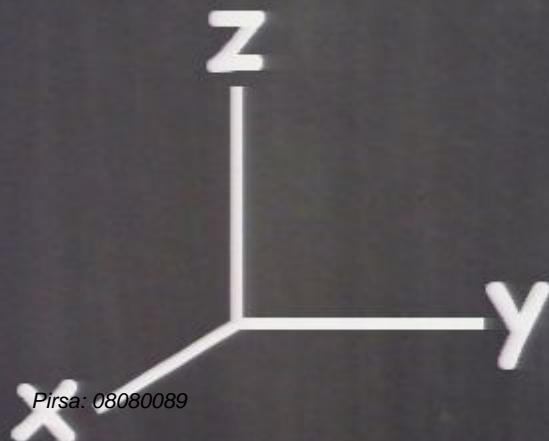
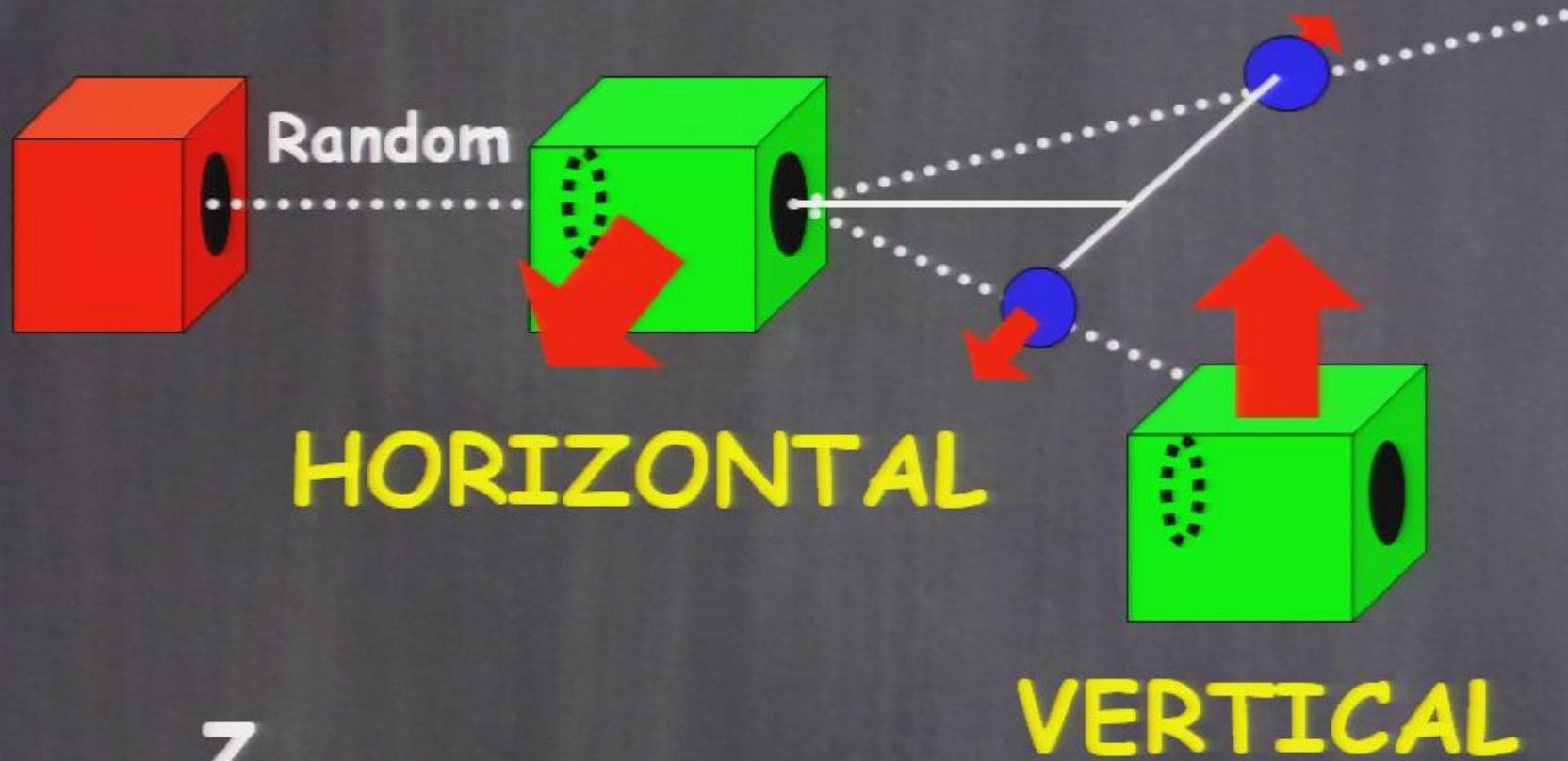
VE



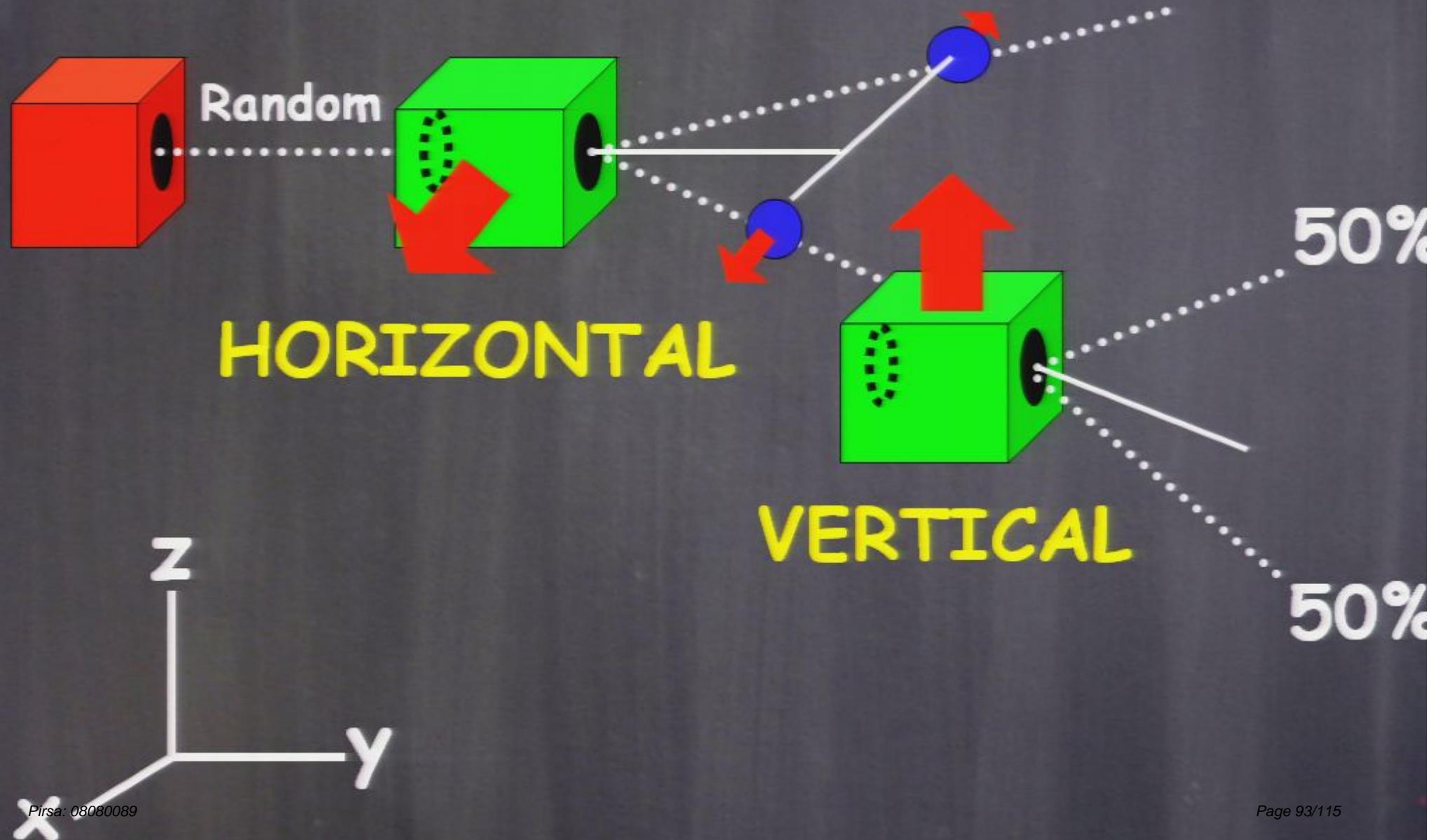
# Experiment #3



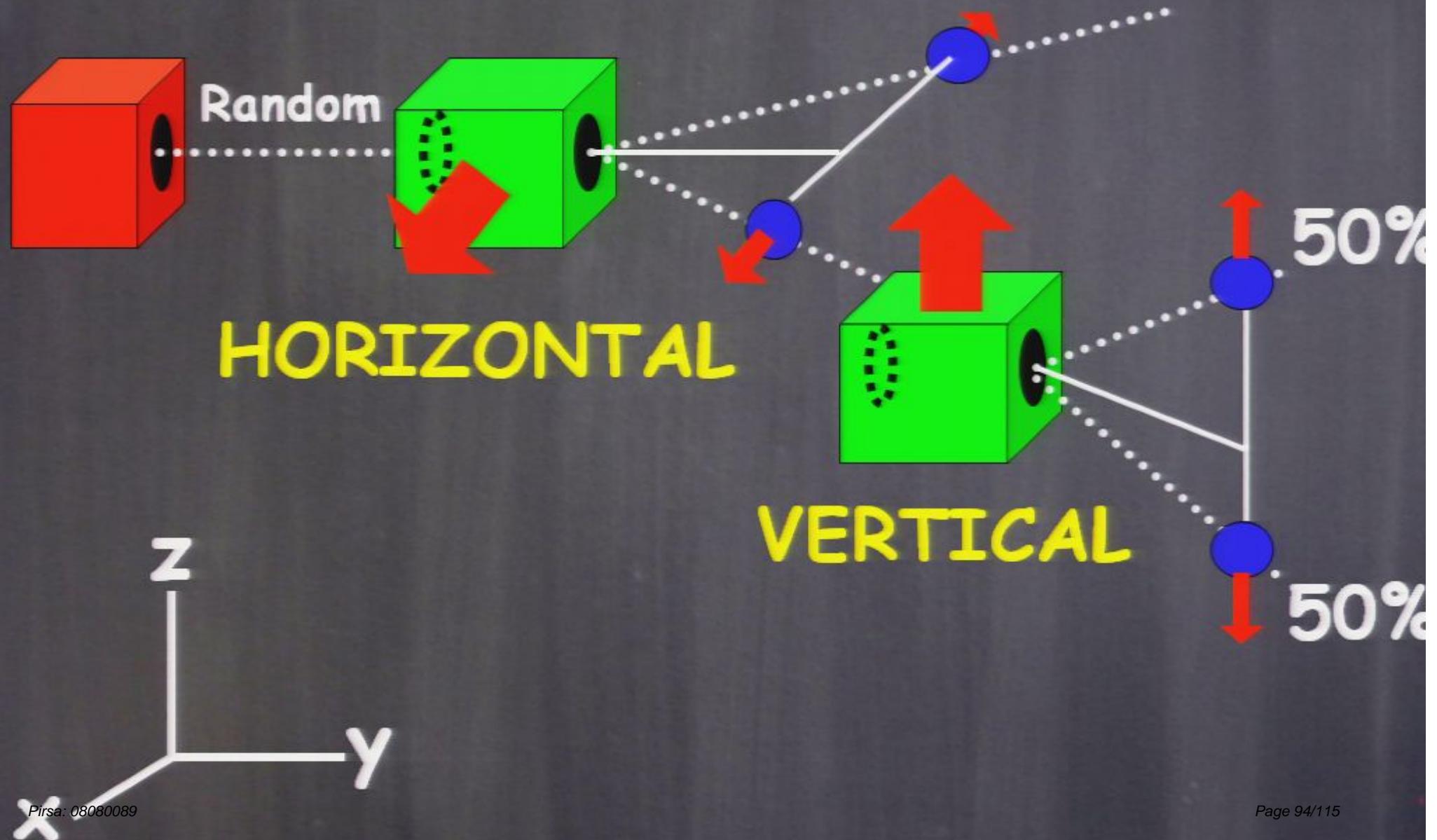
# Experiment #3



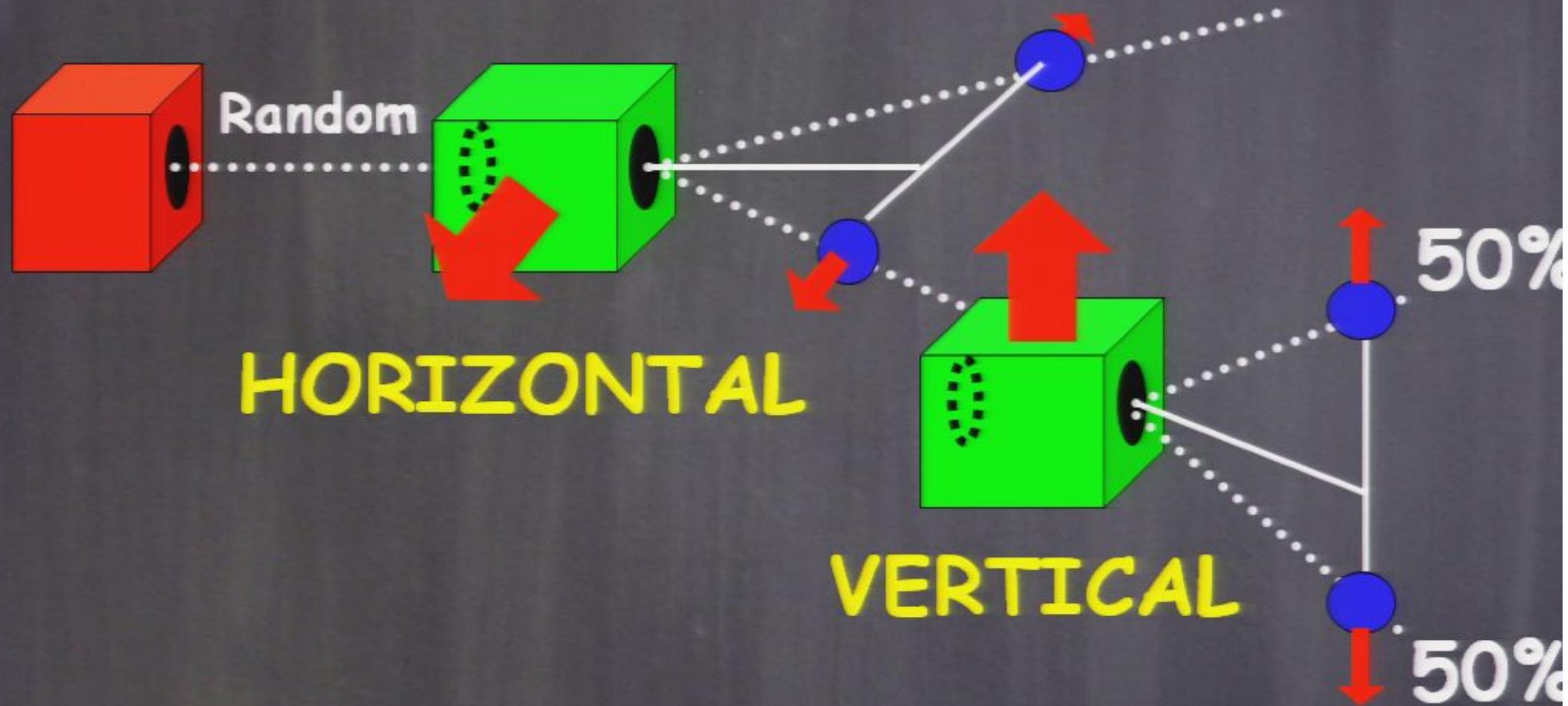
# Experiment #3



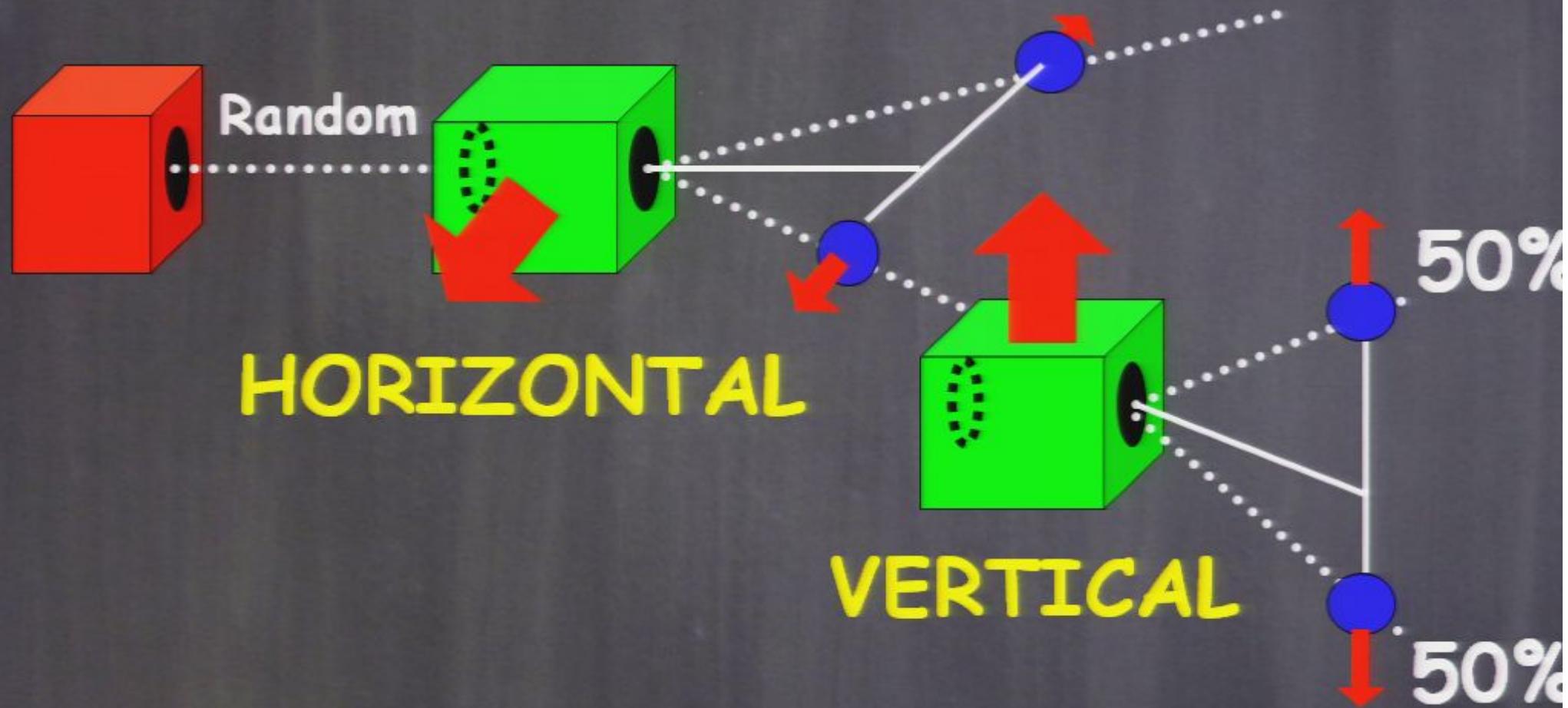
# Experiment #3



# Experiment #3



# Experiment #3



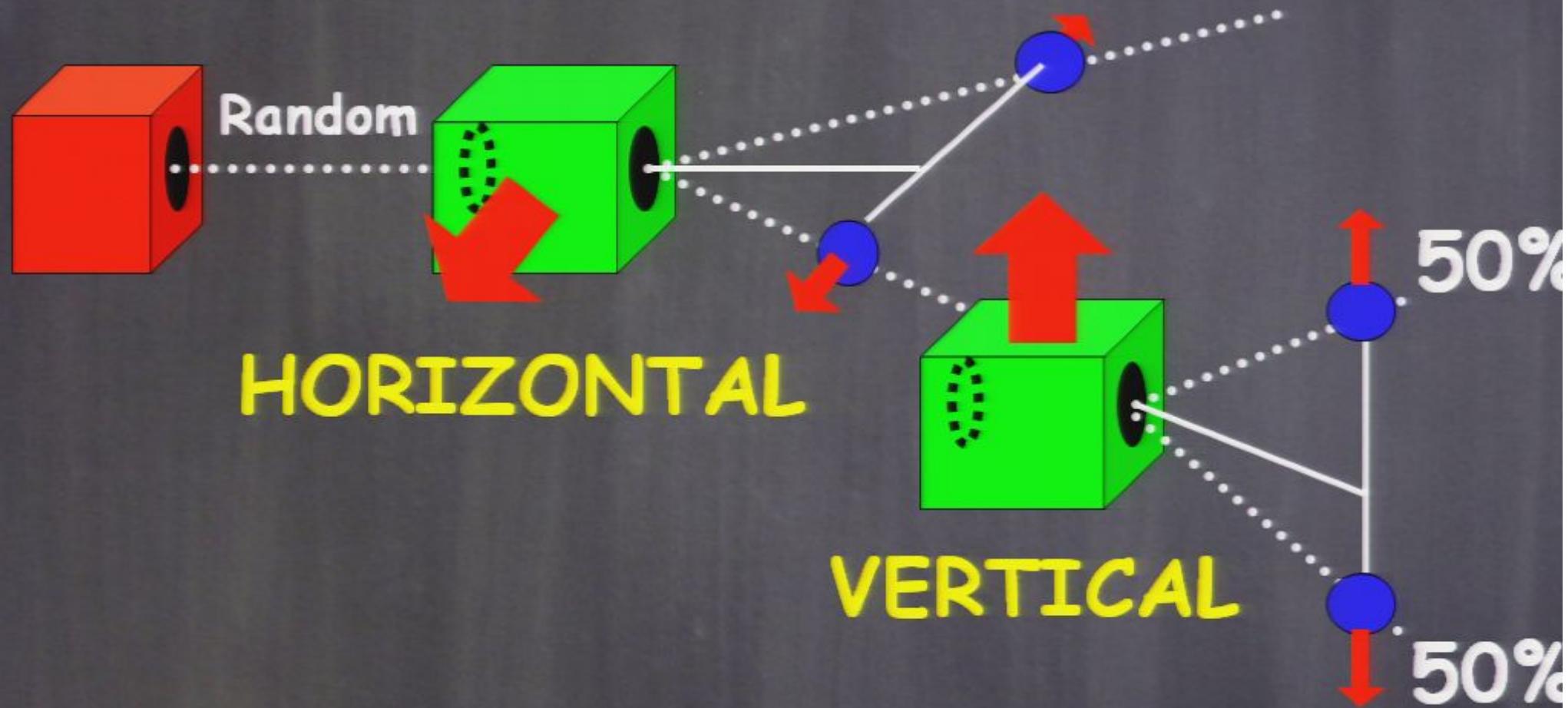
HORIZONTAL

VERTICAL

HORIZONTAL atom has 50/50 CHANCE  
of emerging “spin up” or “spin down”

# Summary of Experiments

# Experiment #3



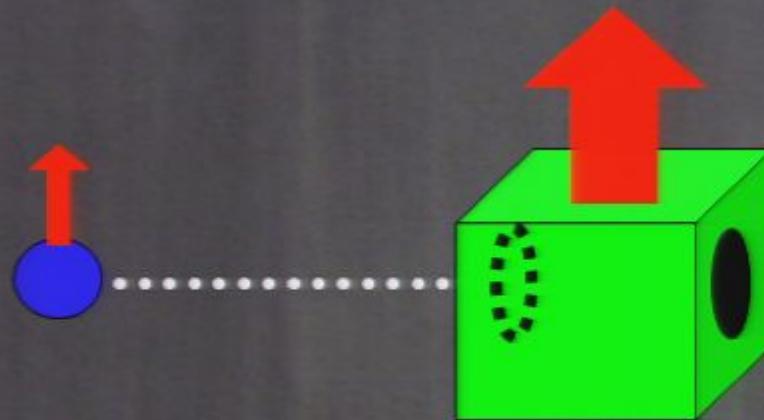
**HORIZONTAL** atom has 50/50 **CHANCE**  
of emerging “spin up” or “spin down”

# Summary of Experiments

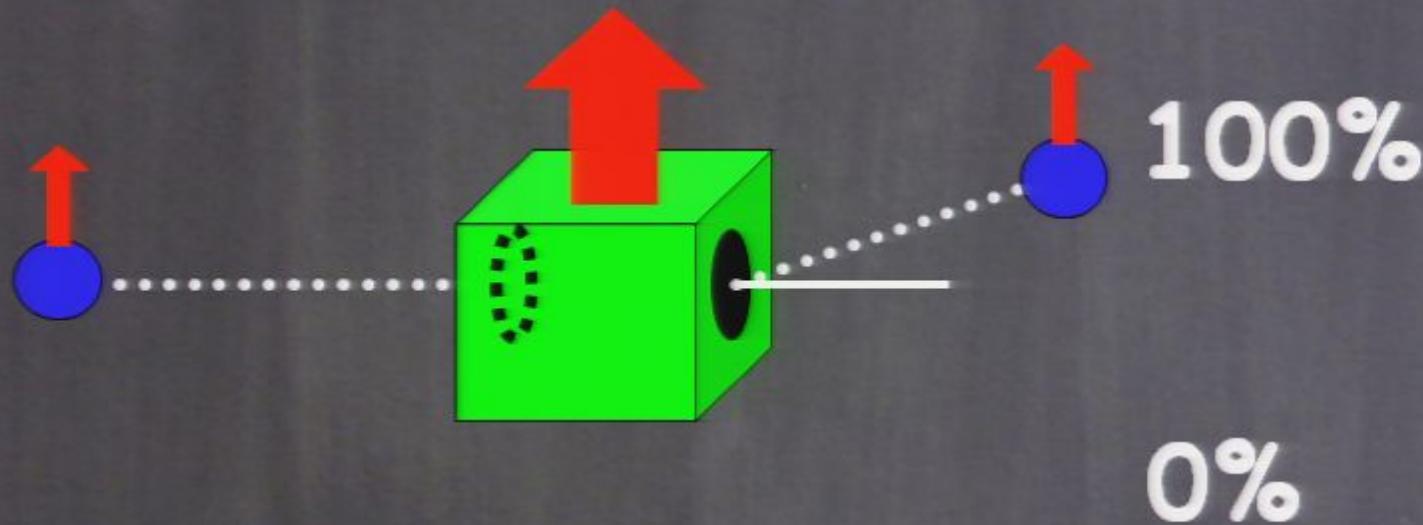
# Summary of Experiments



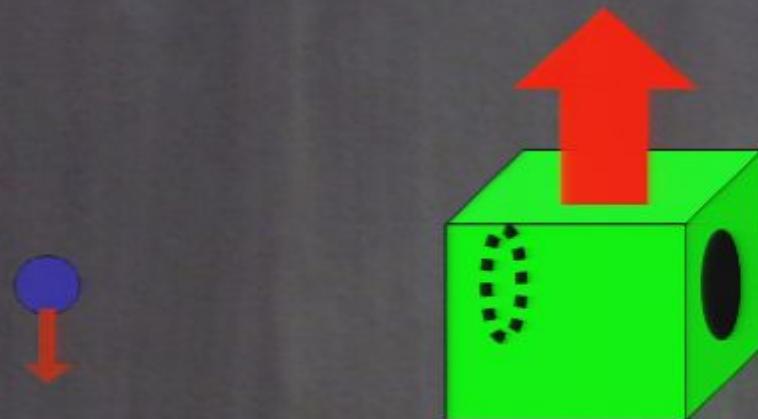
# Summary of Experiments



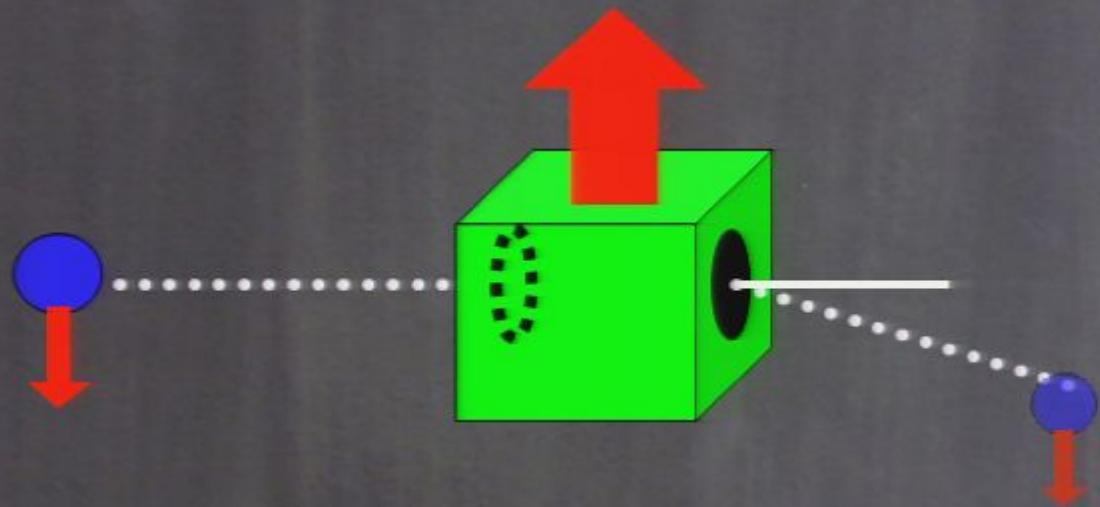
# Summary of Experiments



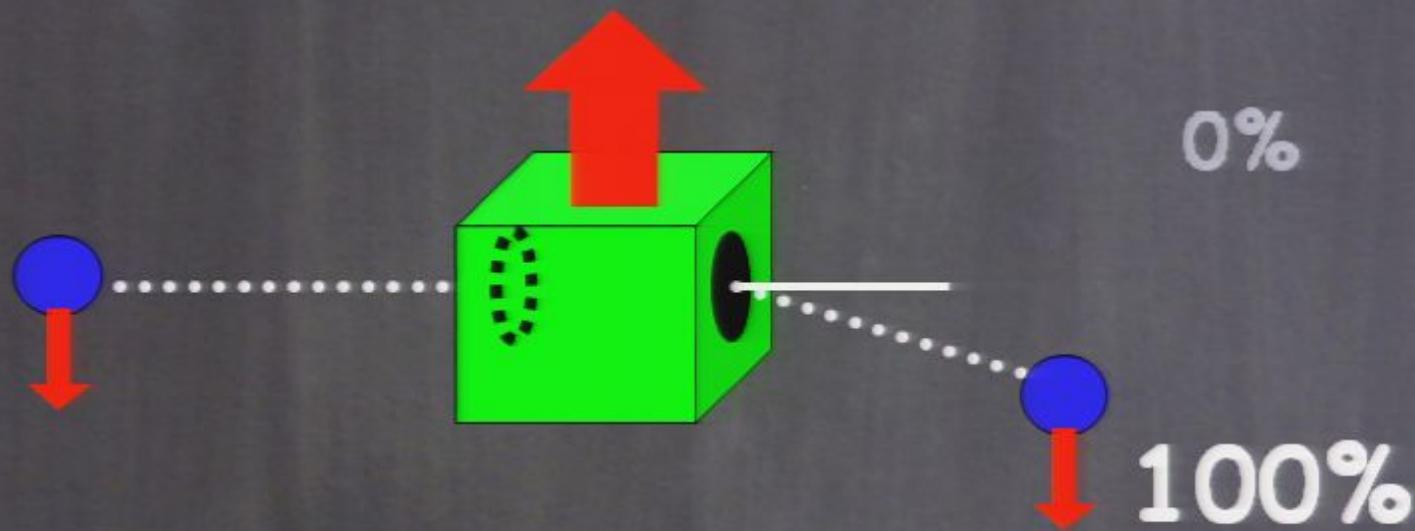
# Summary of Experiments



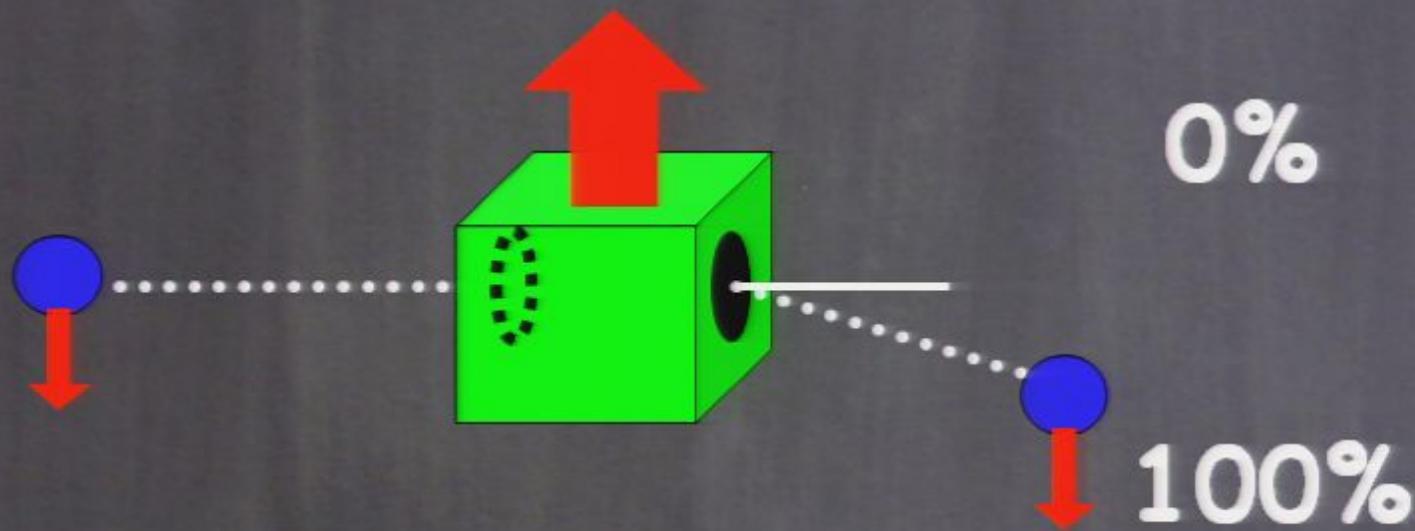
# Summary of Experiments



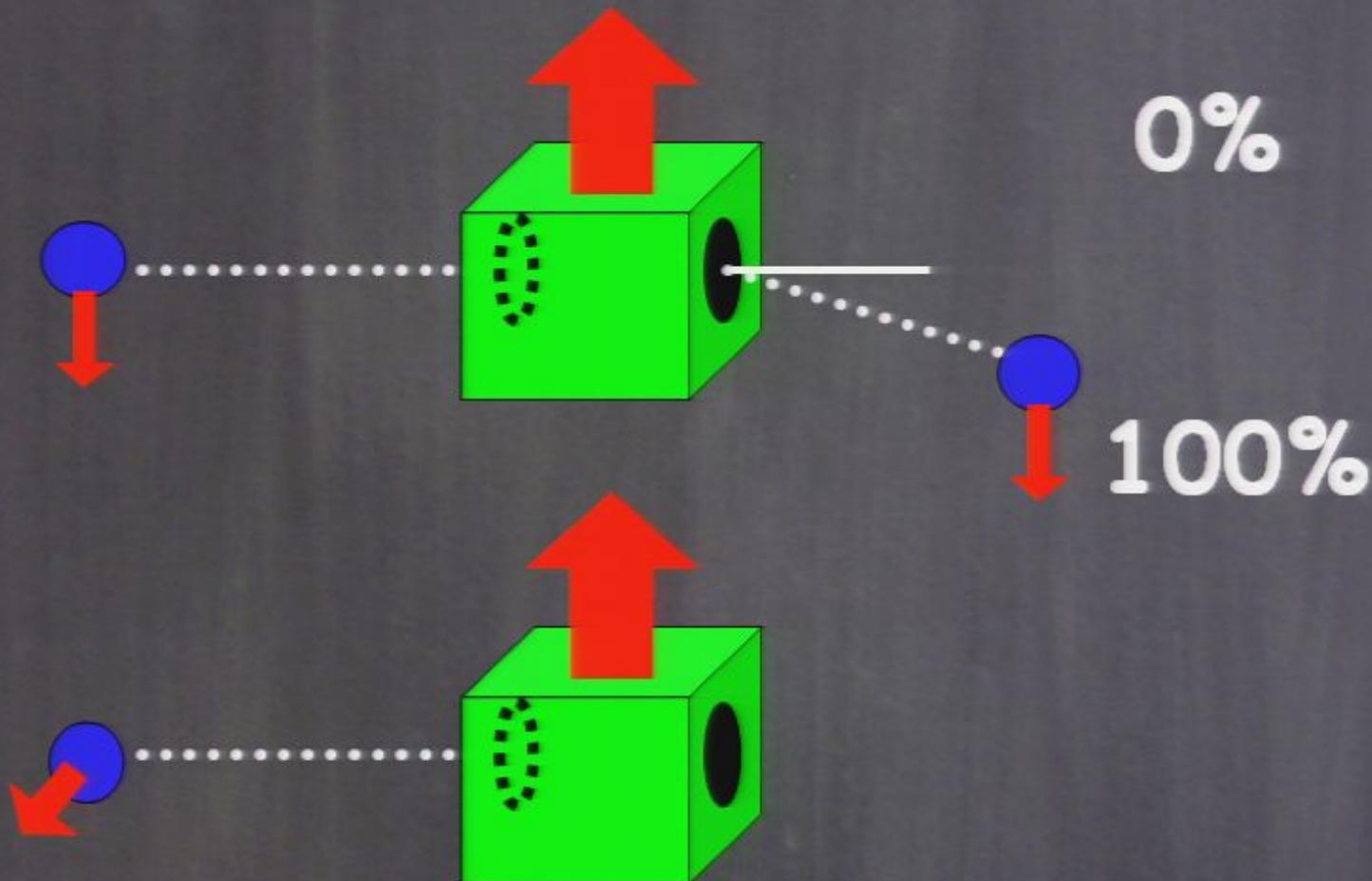
# Summary of Experiments



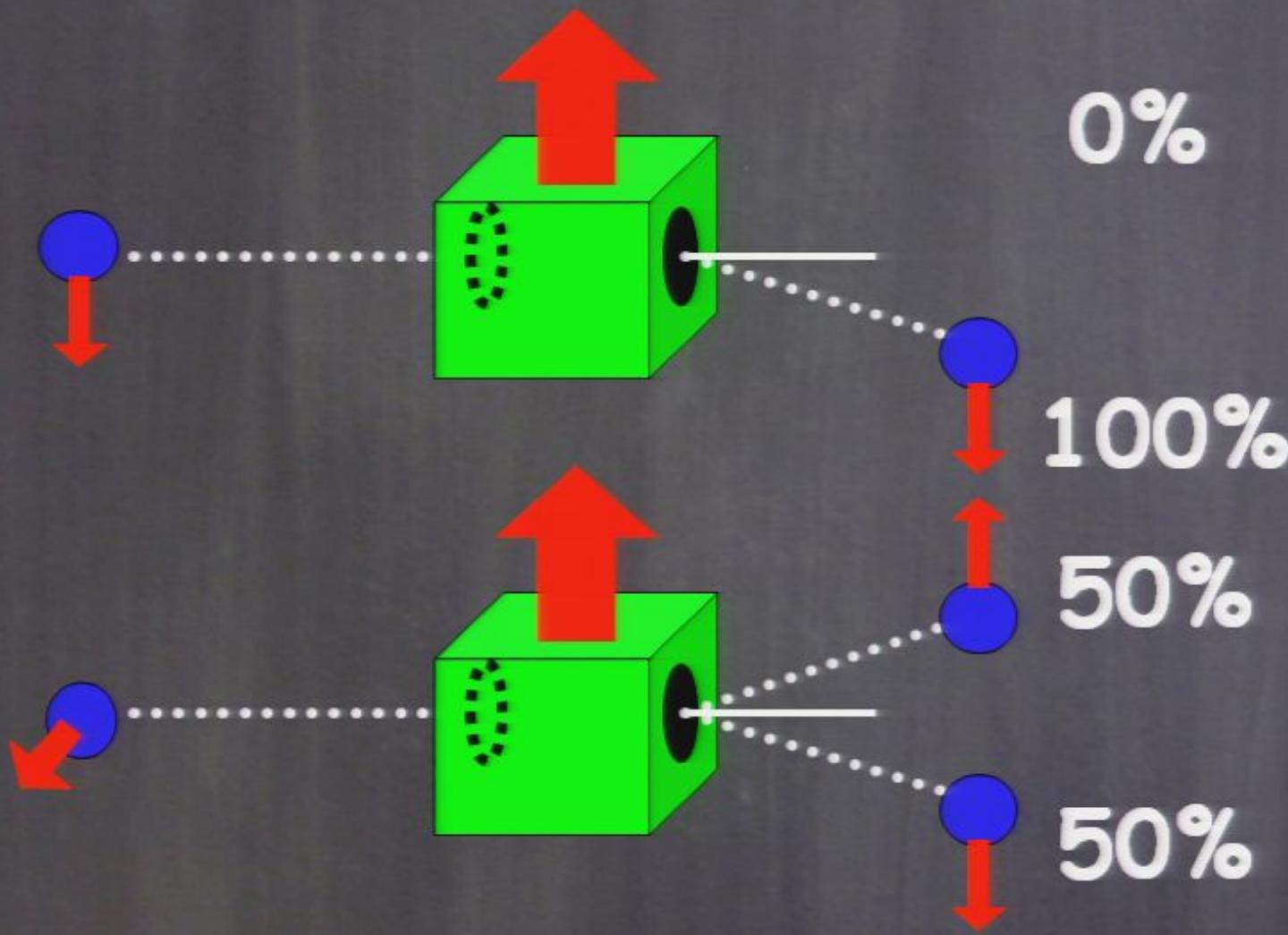
# Summary of Experiments



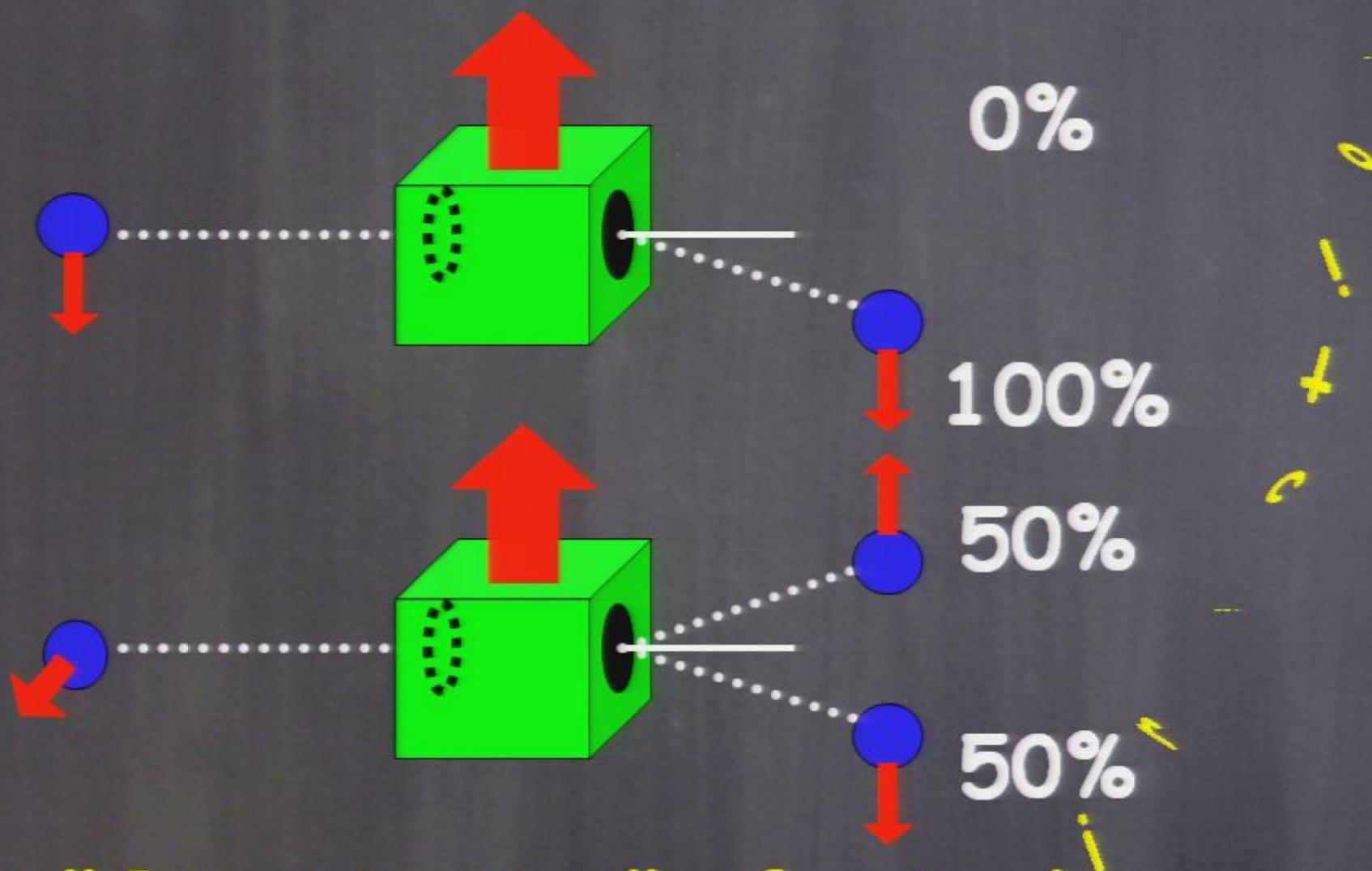
# Summary of Experiments



# Summary of Experiments

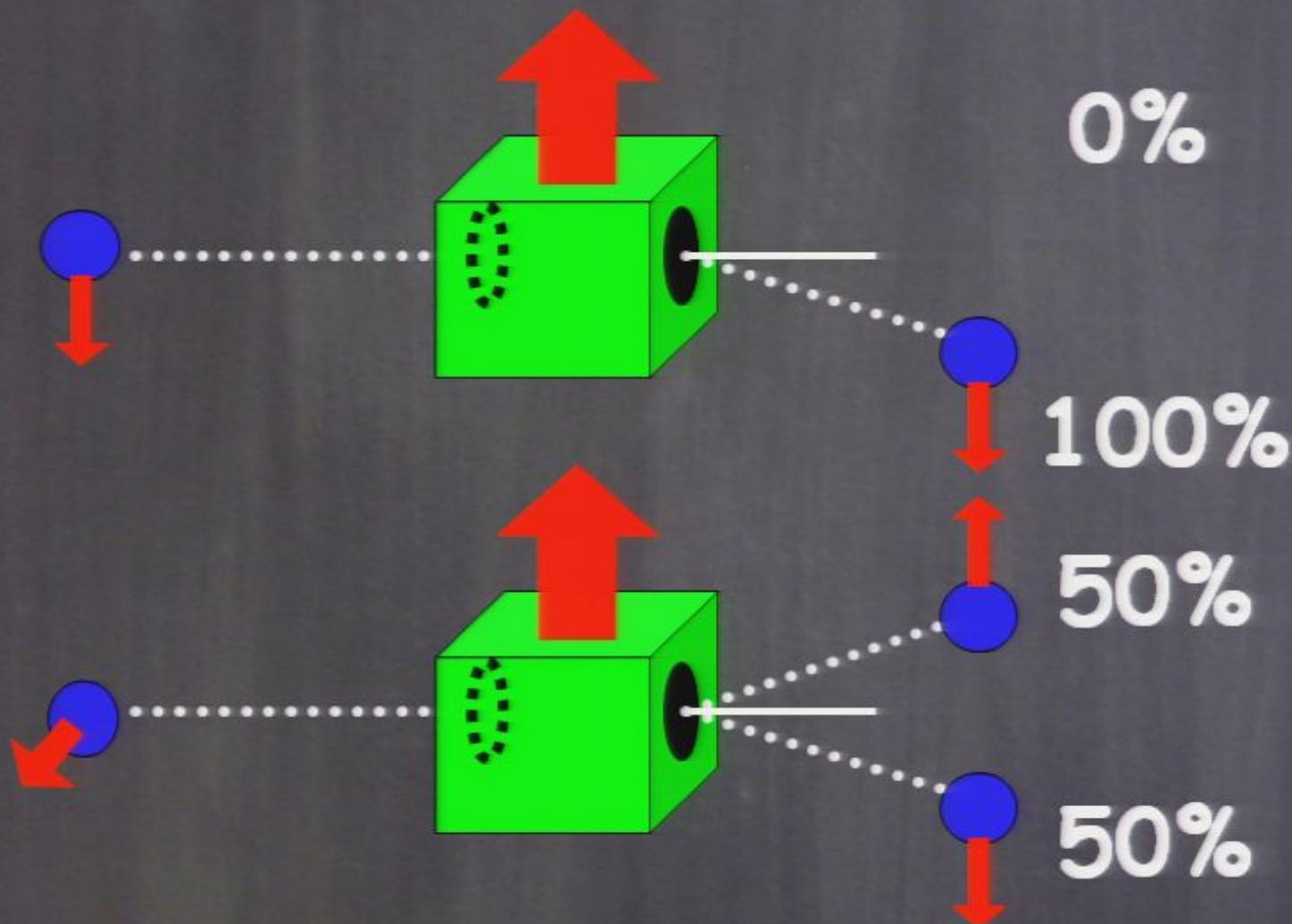


# Summary of Experiments



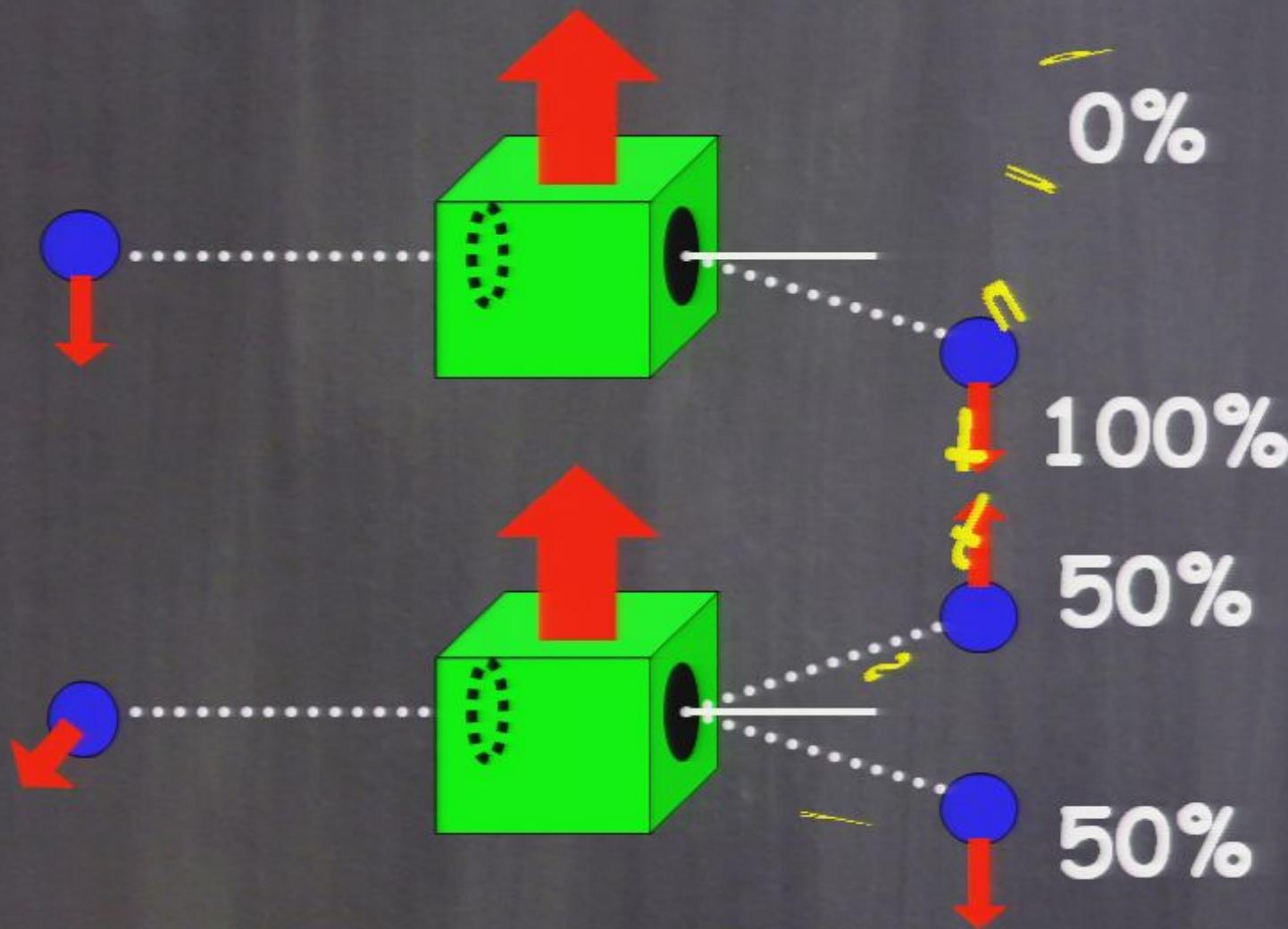
1: "Quantization" of spin d

# Summary of Experiments



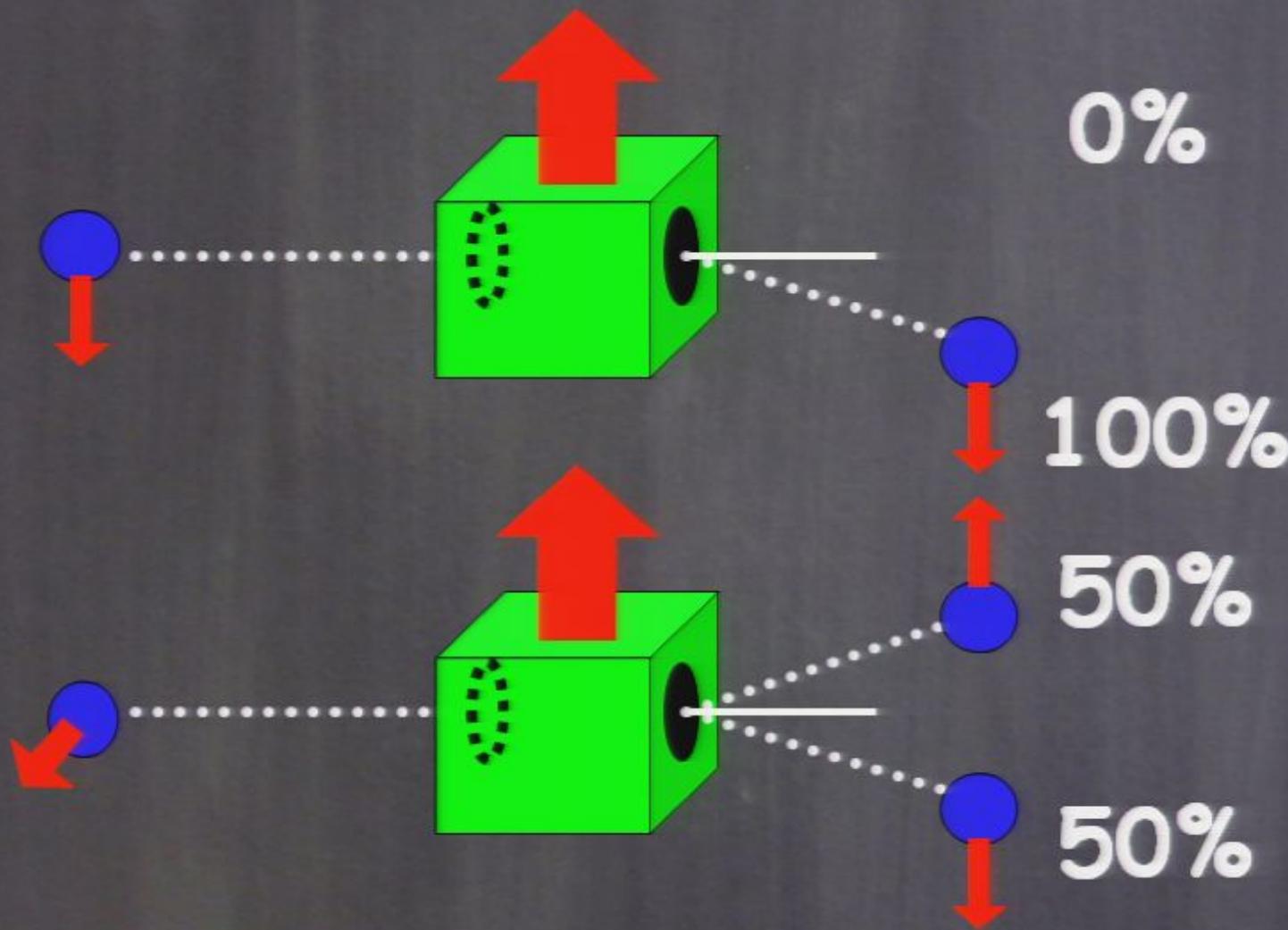
1: “Quantization” of spin direction

# Summary of Experiments



- 1: "Quantization" of spin direction
- 2: Probability  $p^l$

# Summary of Experiments



1: "Quantization" of spin direction

2: Probability plays fundamental role



# The Mathematics of Spin

# The Mathematics of Spin