

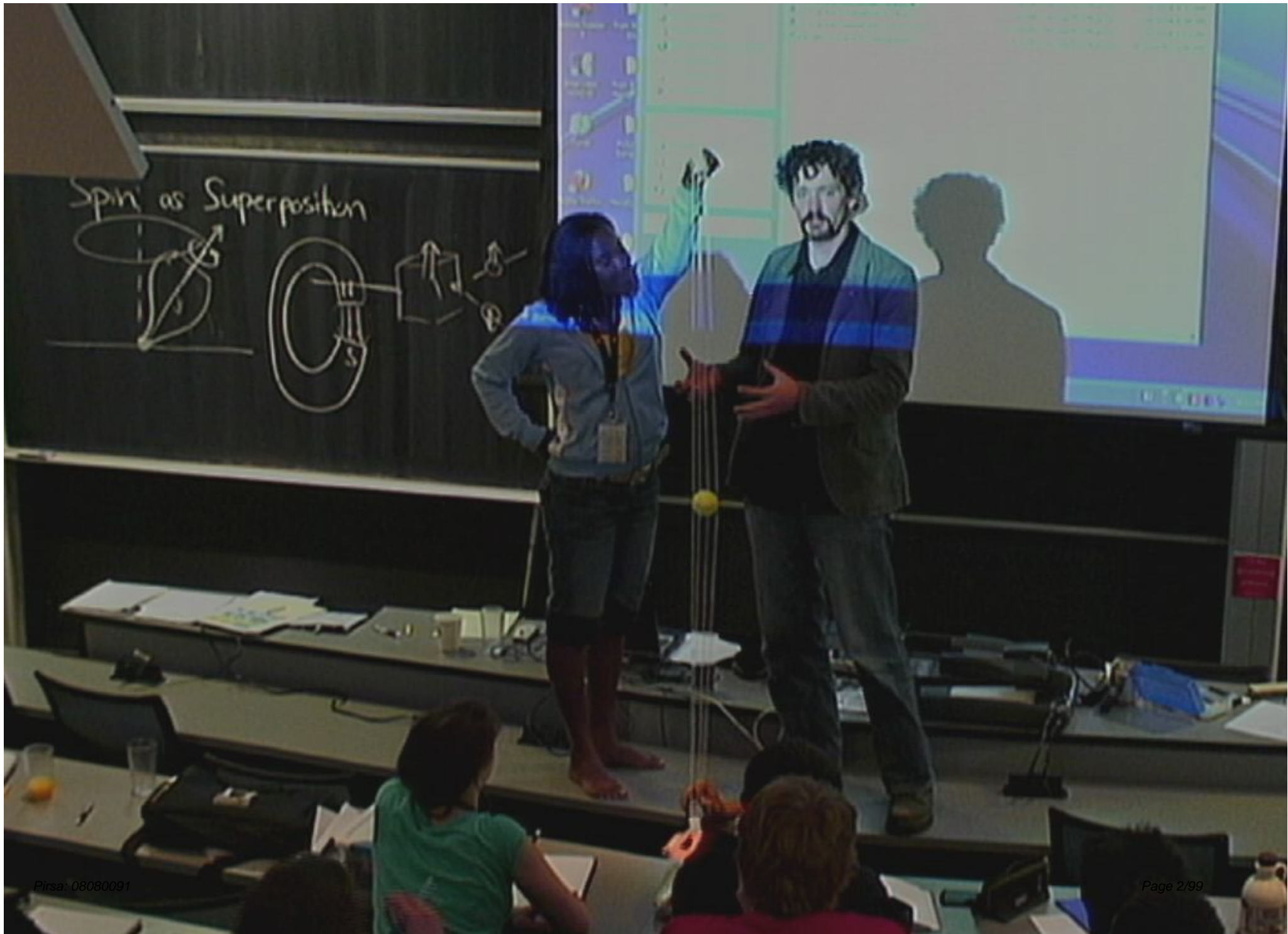
Title: Quantum Mechanics 16 - The Quantum Nature of the Electron: Superposition and Entanglement

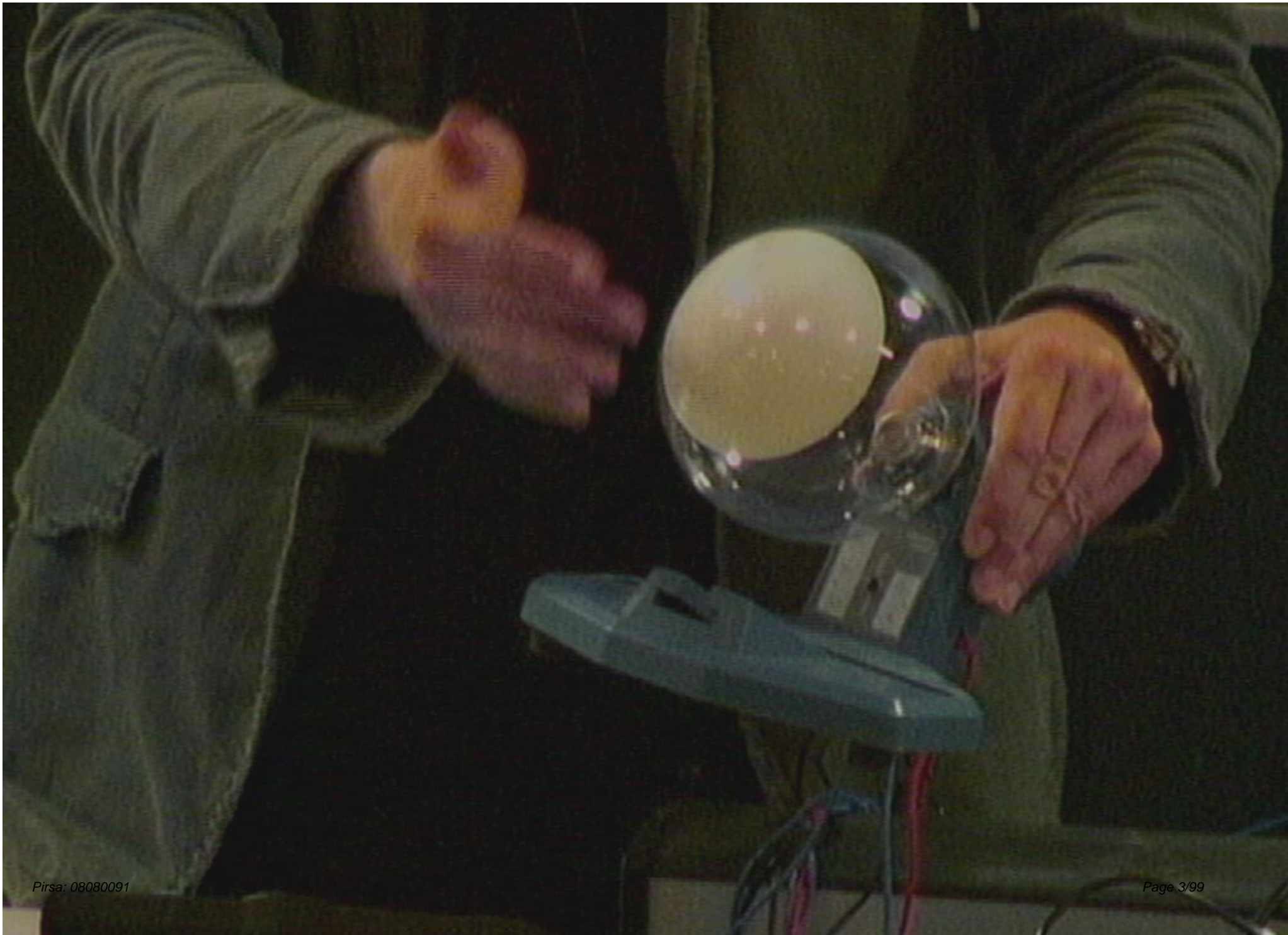
Date: Aug 10, 2008 03:30 PM

URL: <http://pirsa.org/08080091>

Abstract: A demonstration of electron superposition using an electron diffraction apparatus, plus an introduction to quantum entanglement.
Learning Outcomes:

• Concrete demonstration related to the surprising 360/720 degree prediction discussed in QM-15.
• Understanding how an electron diffraction apparatus works, and how its surprising experimental results are explained by electron superposition, i.e. the electron behaving as if it can exist in multiple paths simultaneously.
• Understanding how superposition applied to two particles can lead to a remarkable phenomenon called quantum entanglement (or, as Einstein called it, "spooky action at a distance").



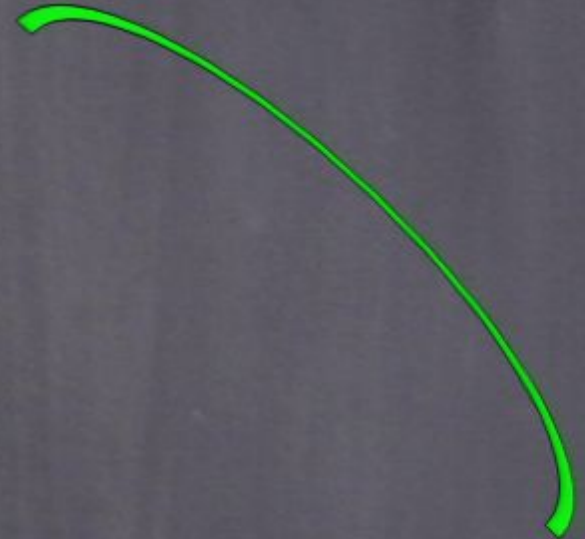




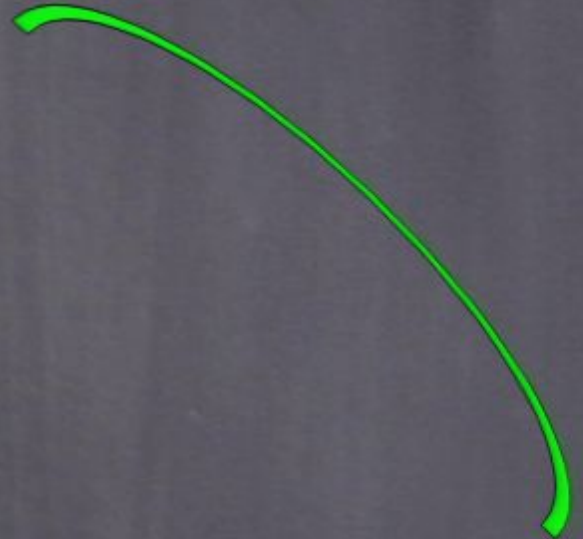
What's Inside the Tube?



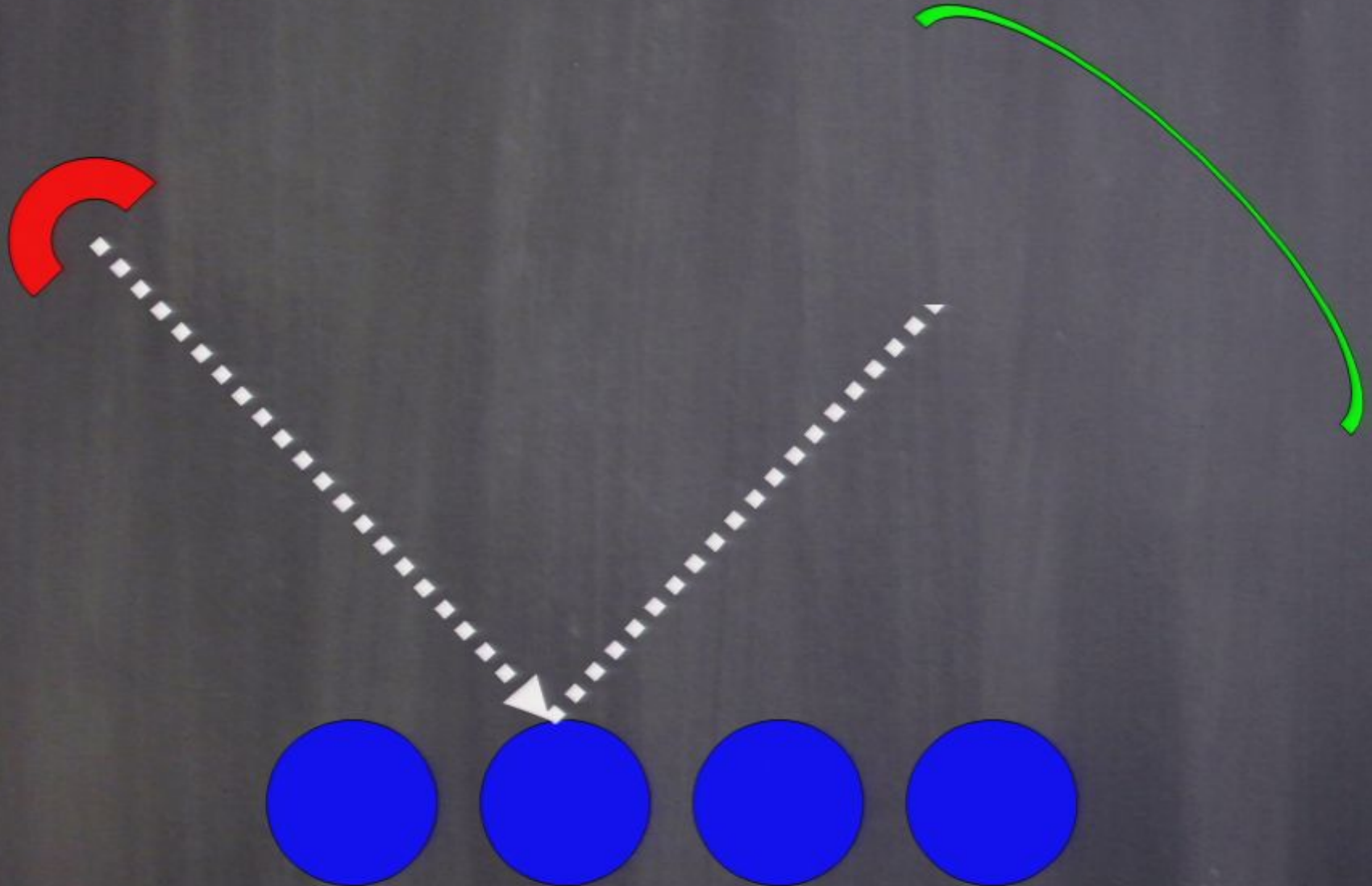
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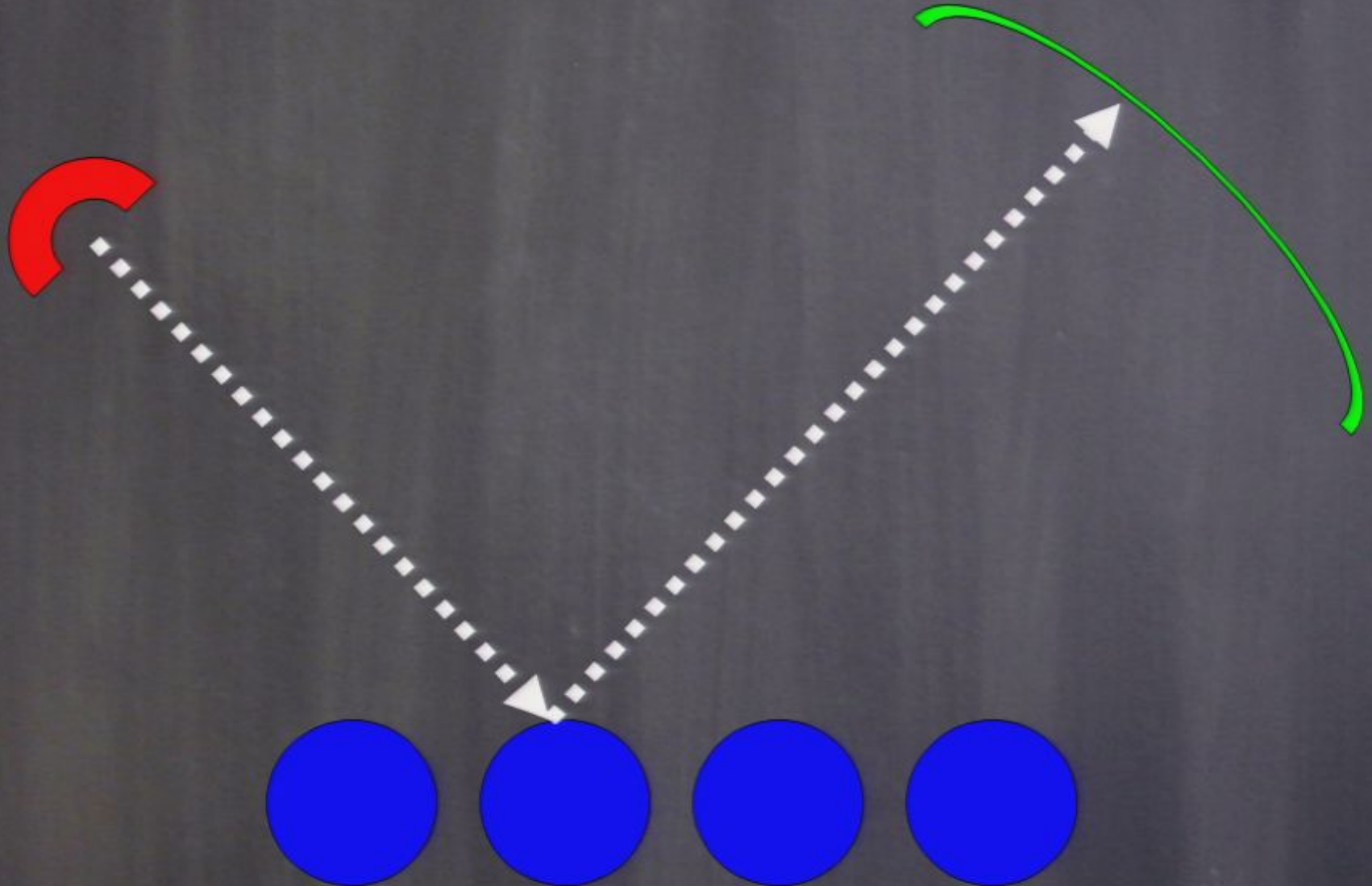
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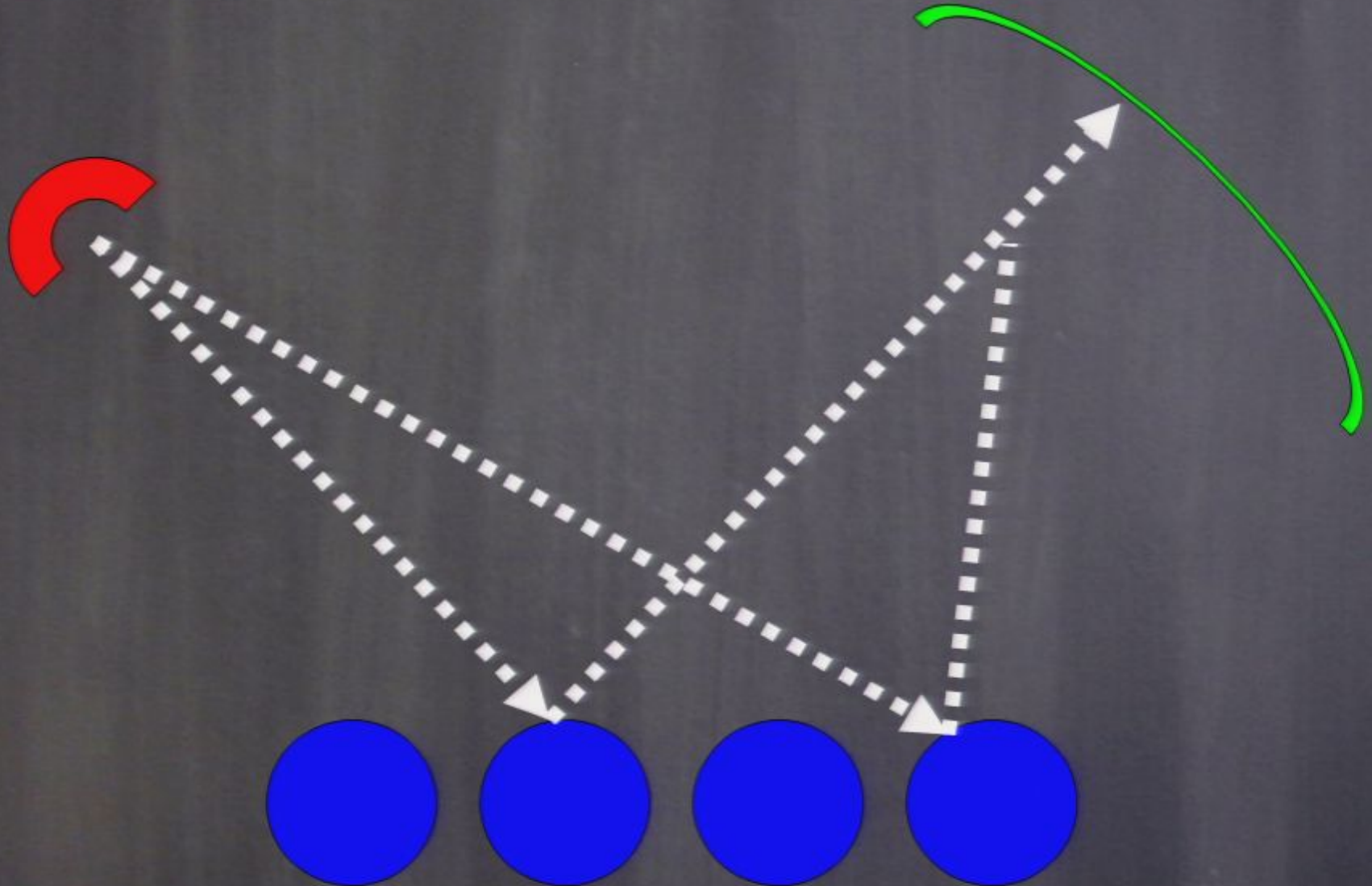
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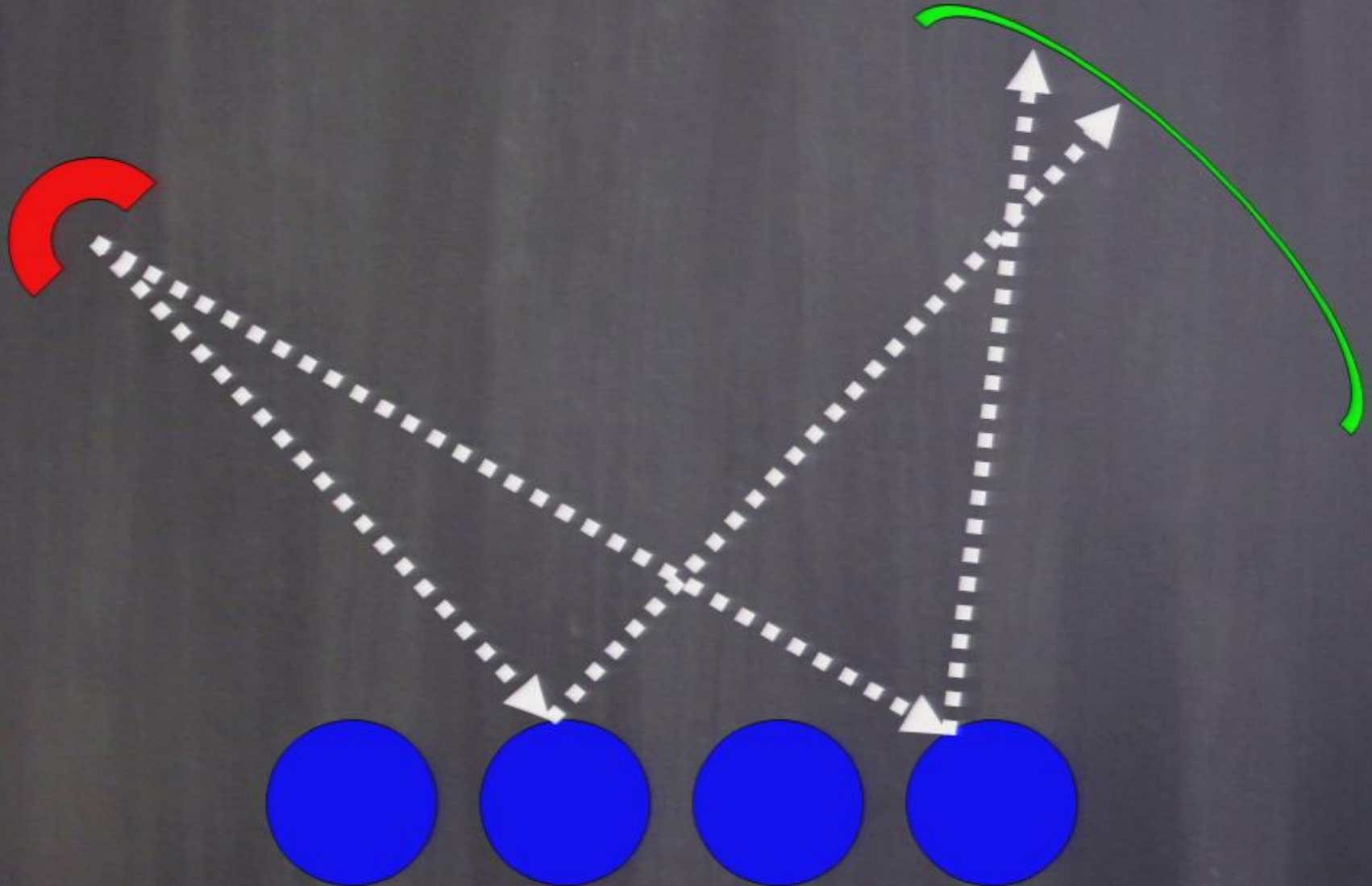
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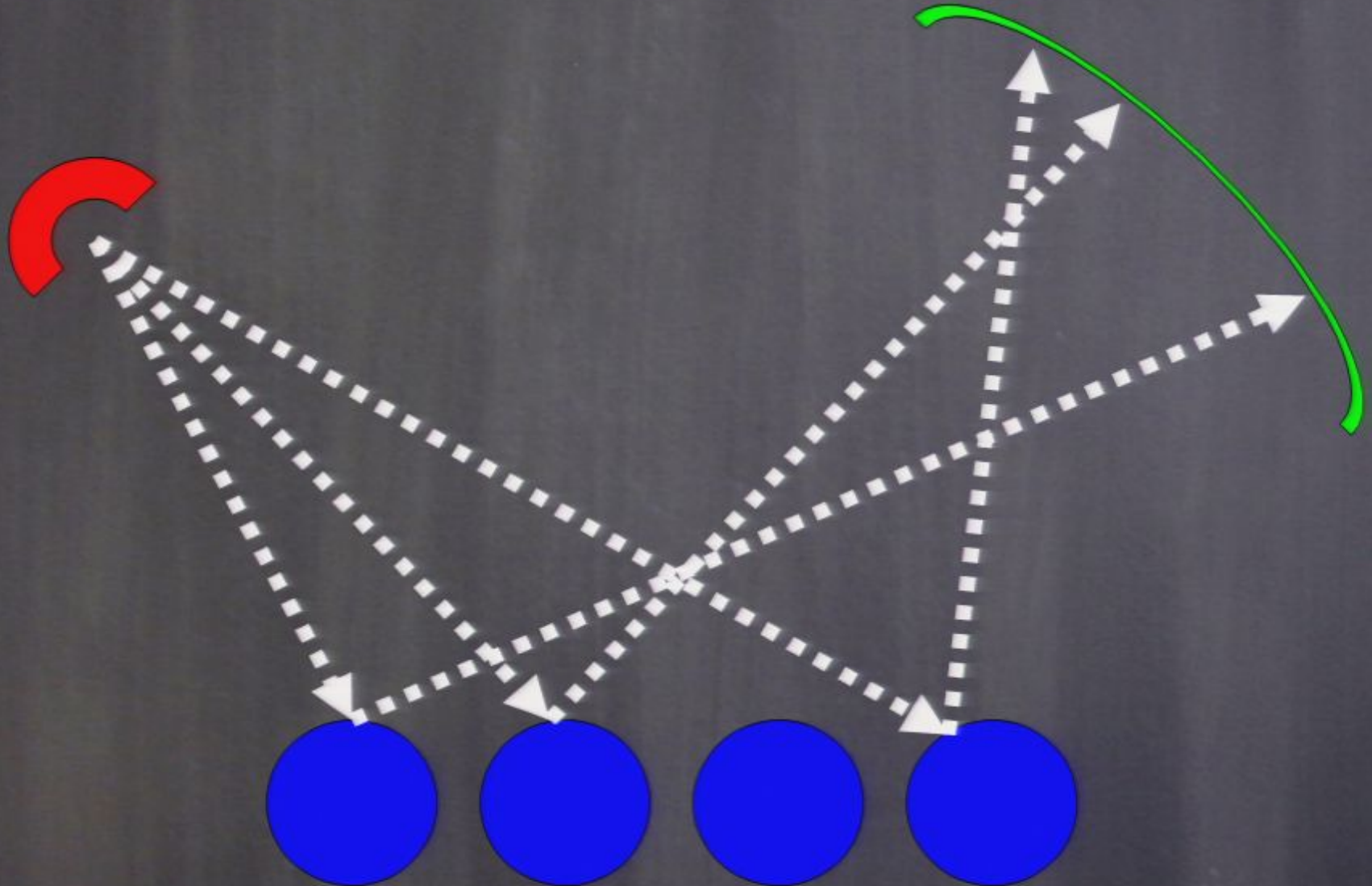
What's Inside the Tube?



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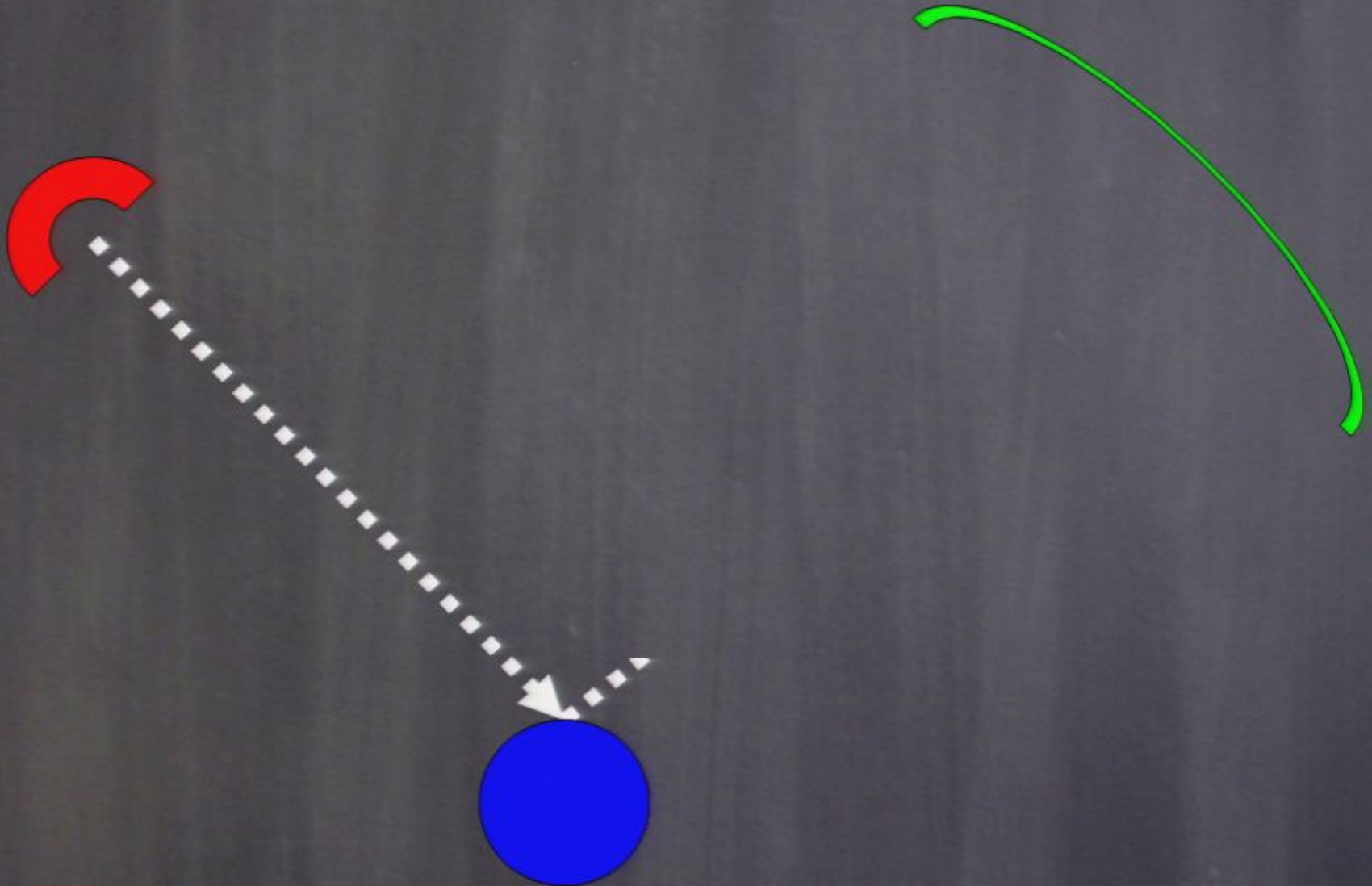
Simplify: Only **ONE** Atom



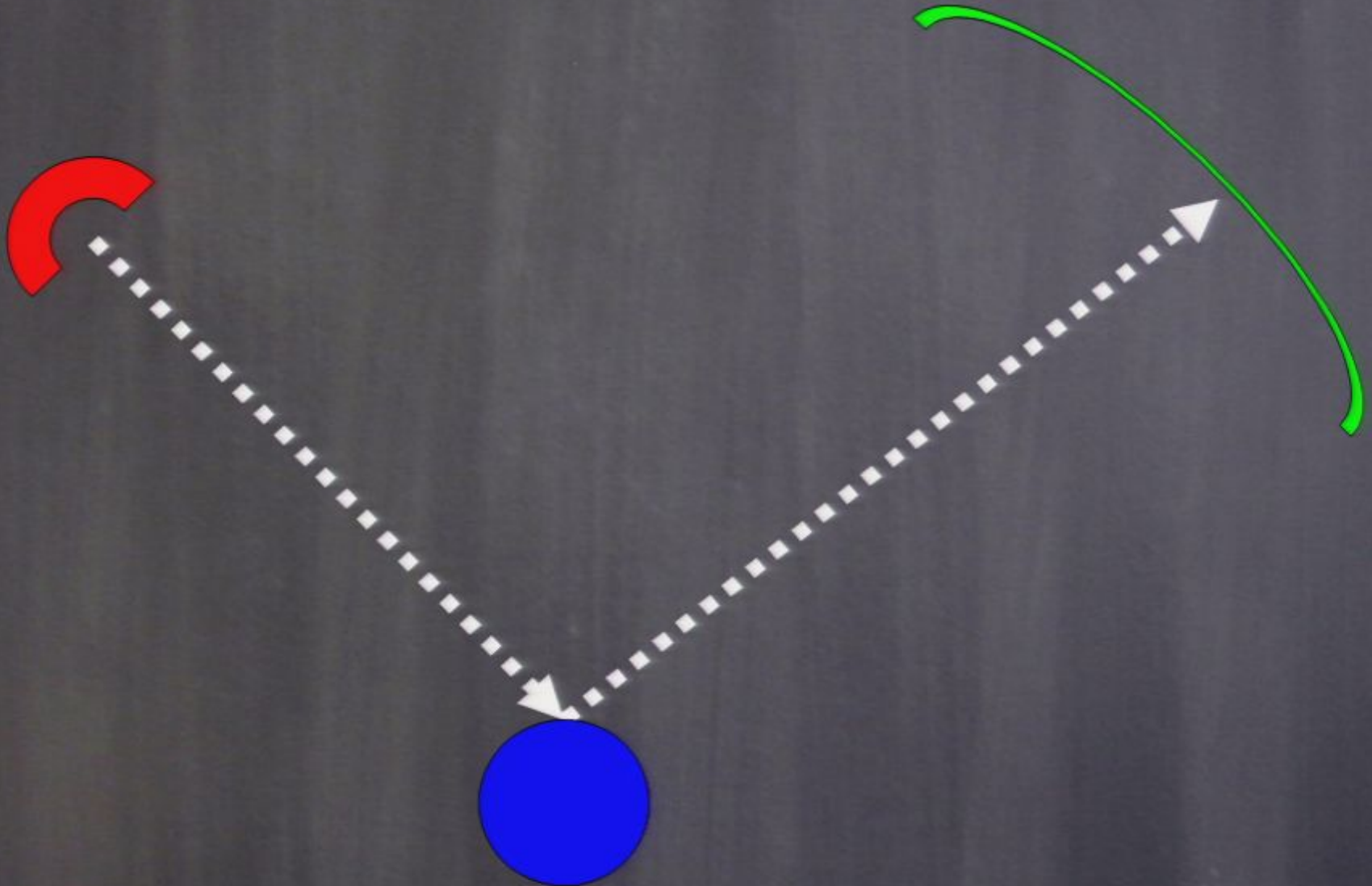
Simplify: Only **ONE** Atom



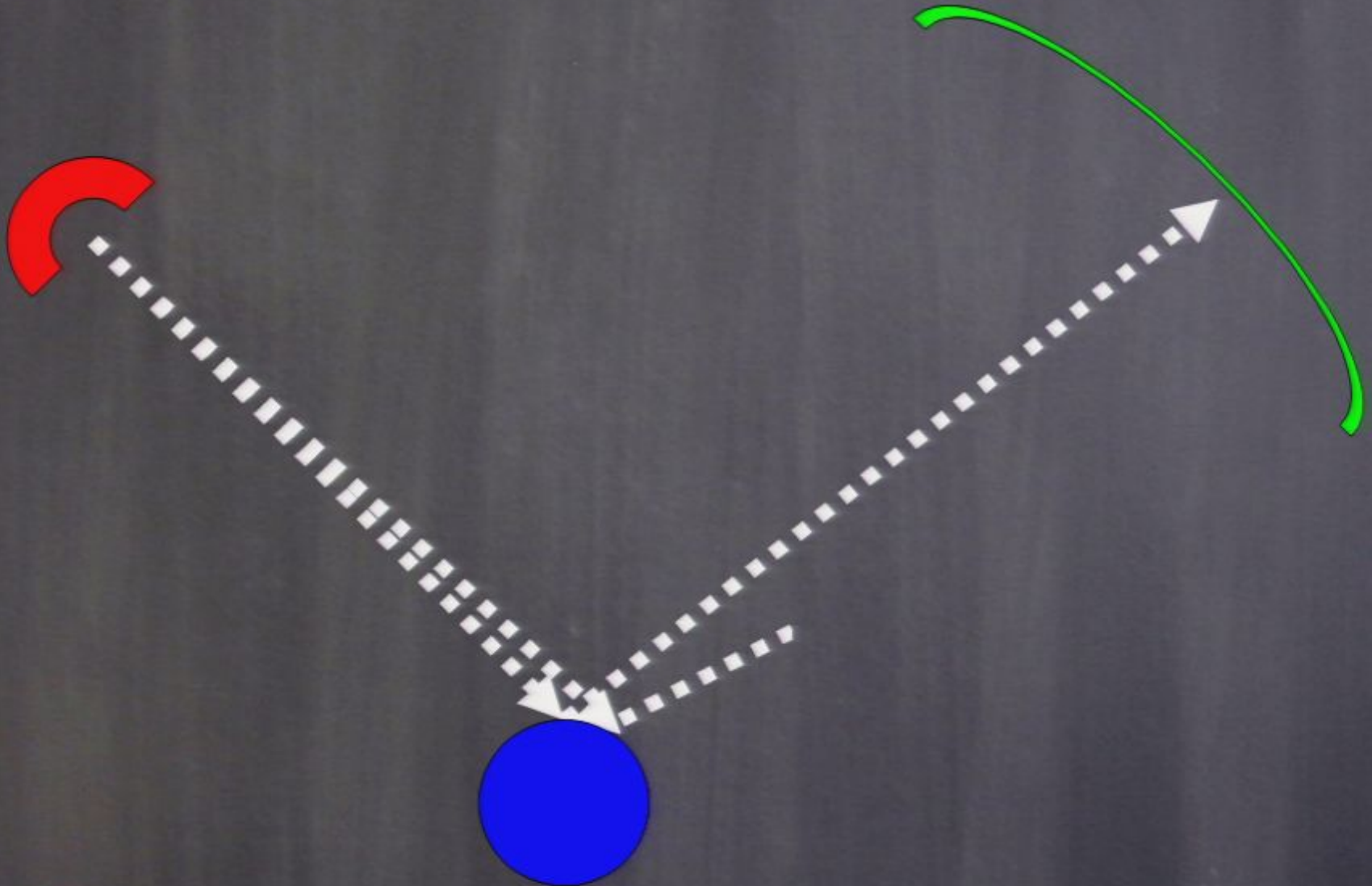
Simplify: Only **ONE** Atom



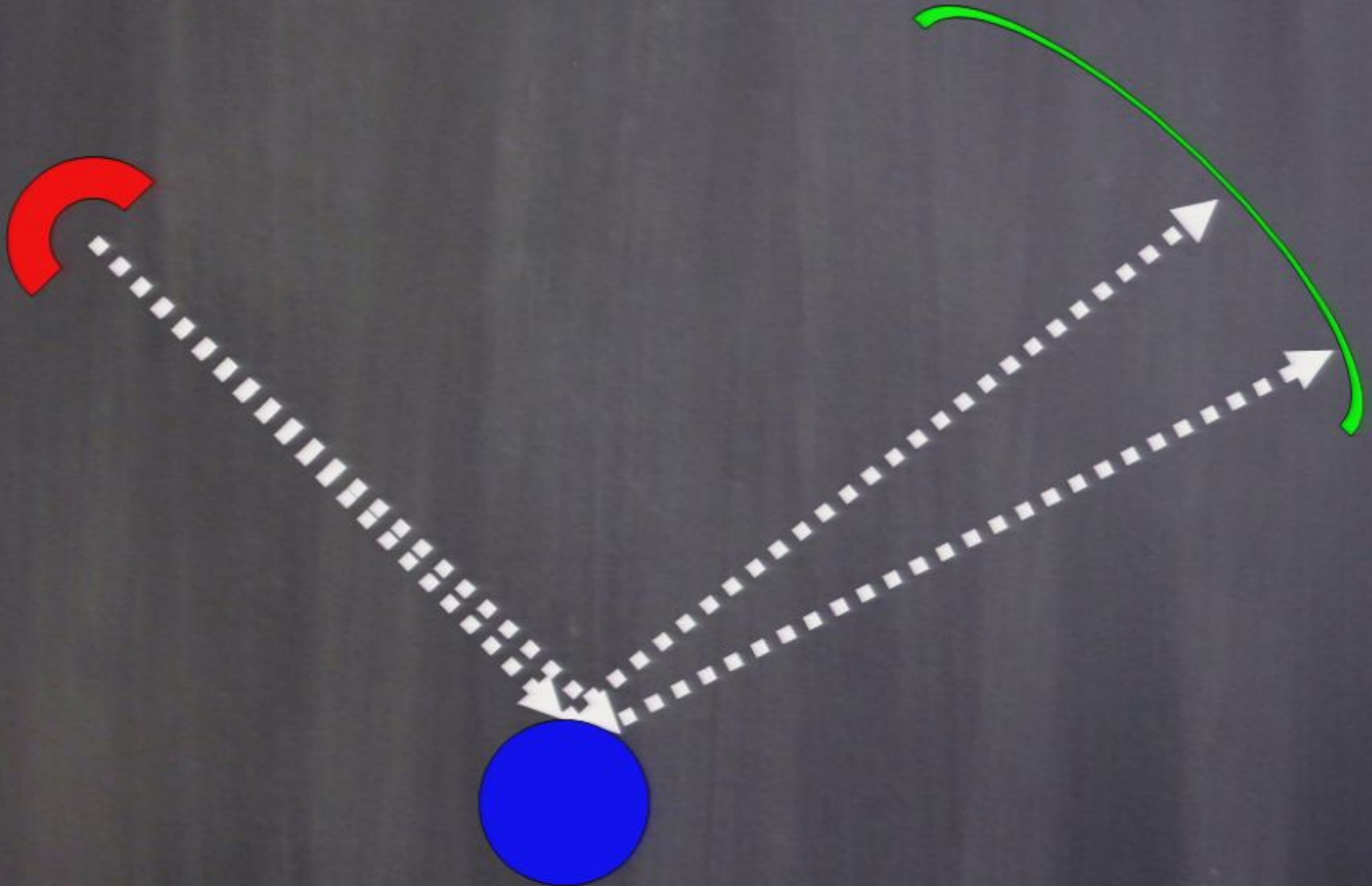
Simplify: Only **ONE** Atom



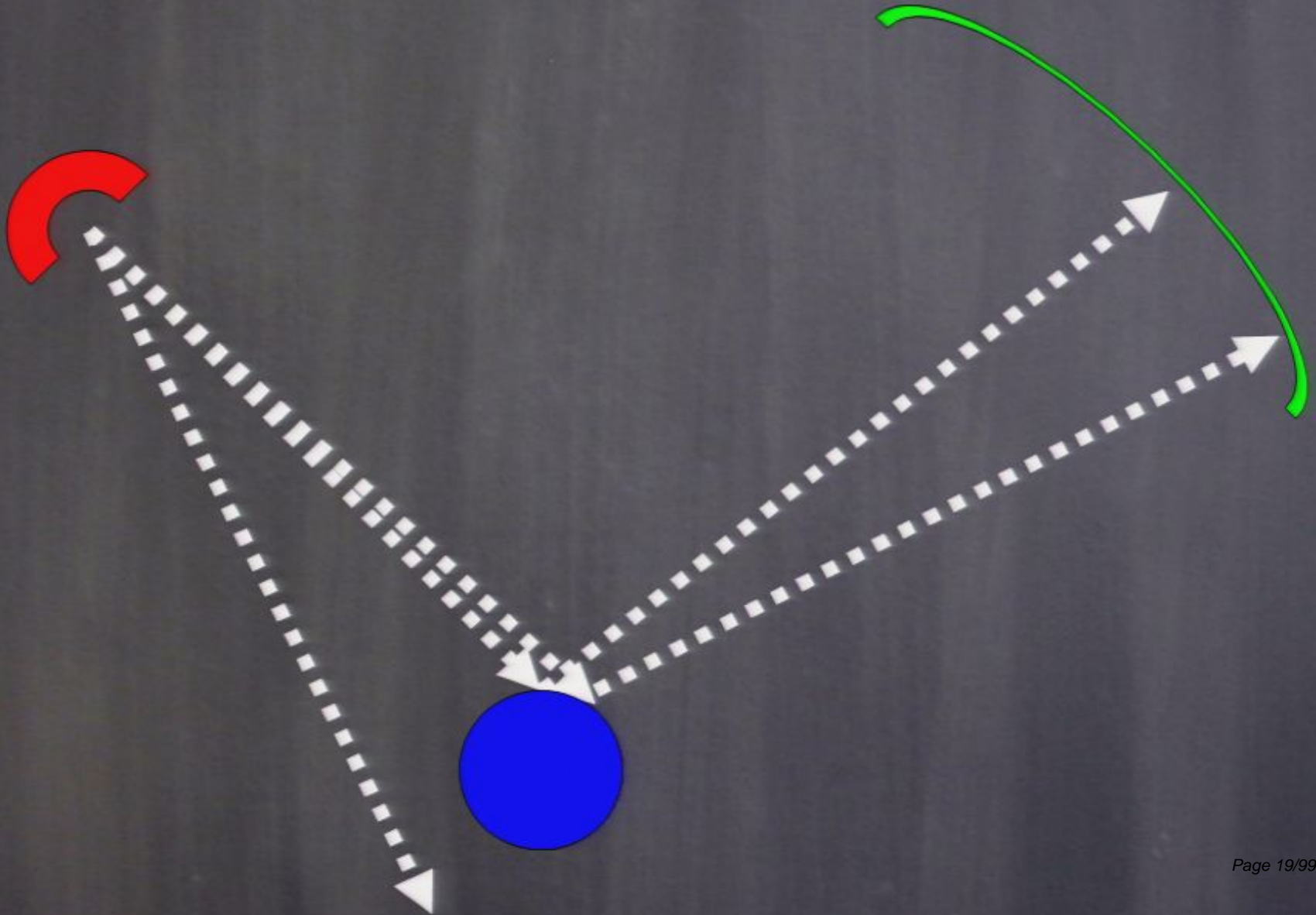
Simplify: Only **ONE** Atom



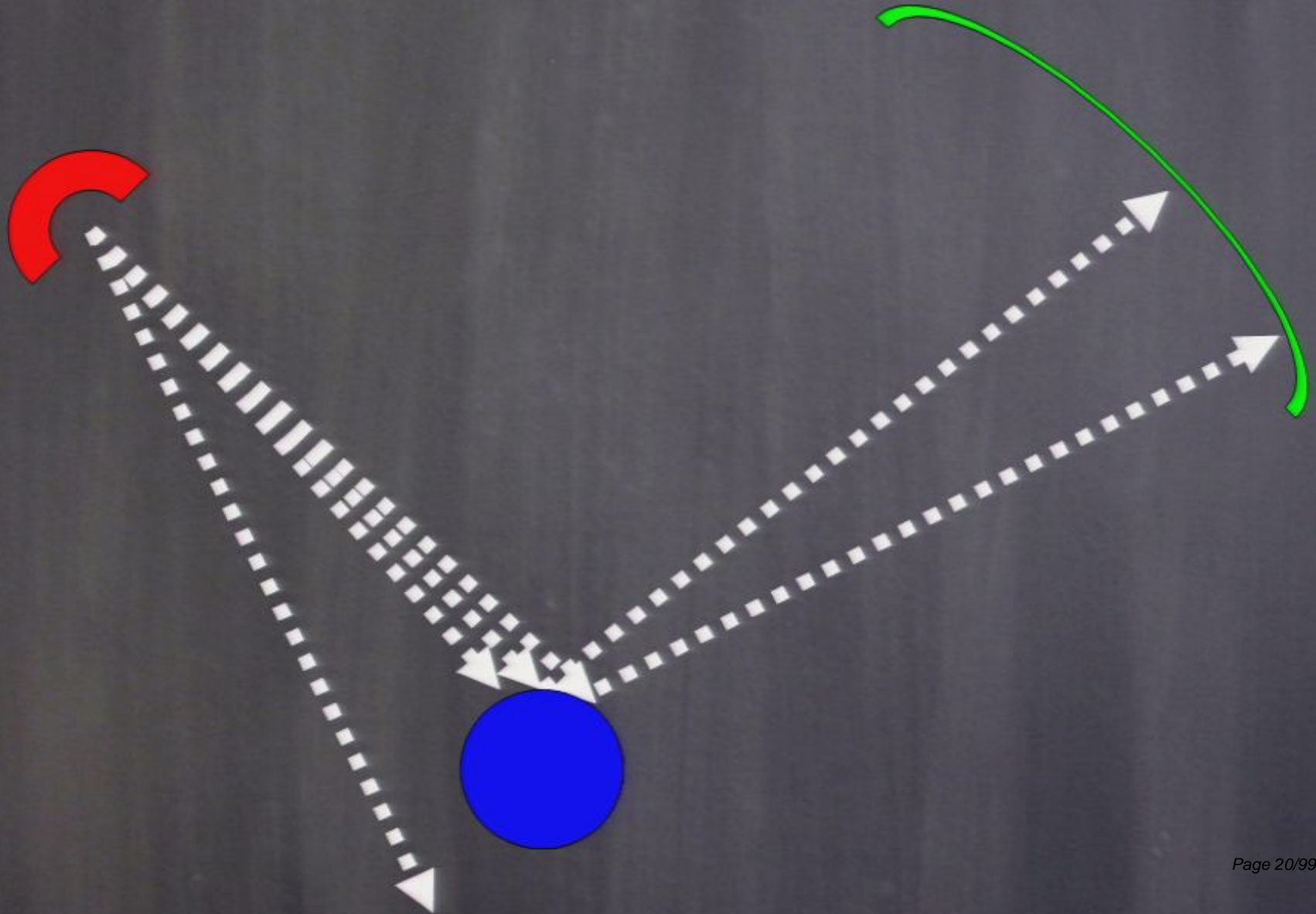
Simplify: Only **ONE** Atom



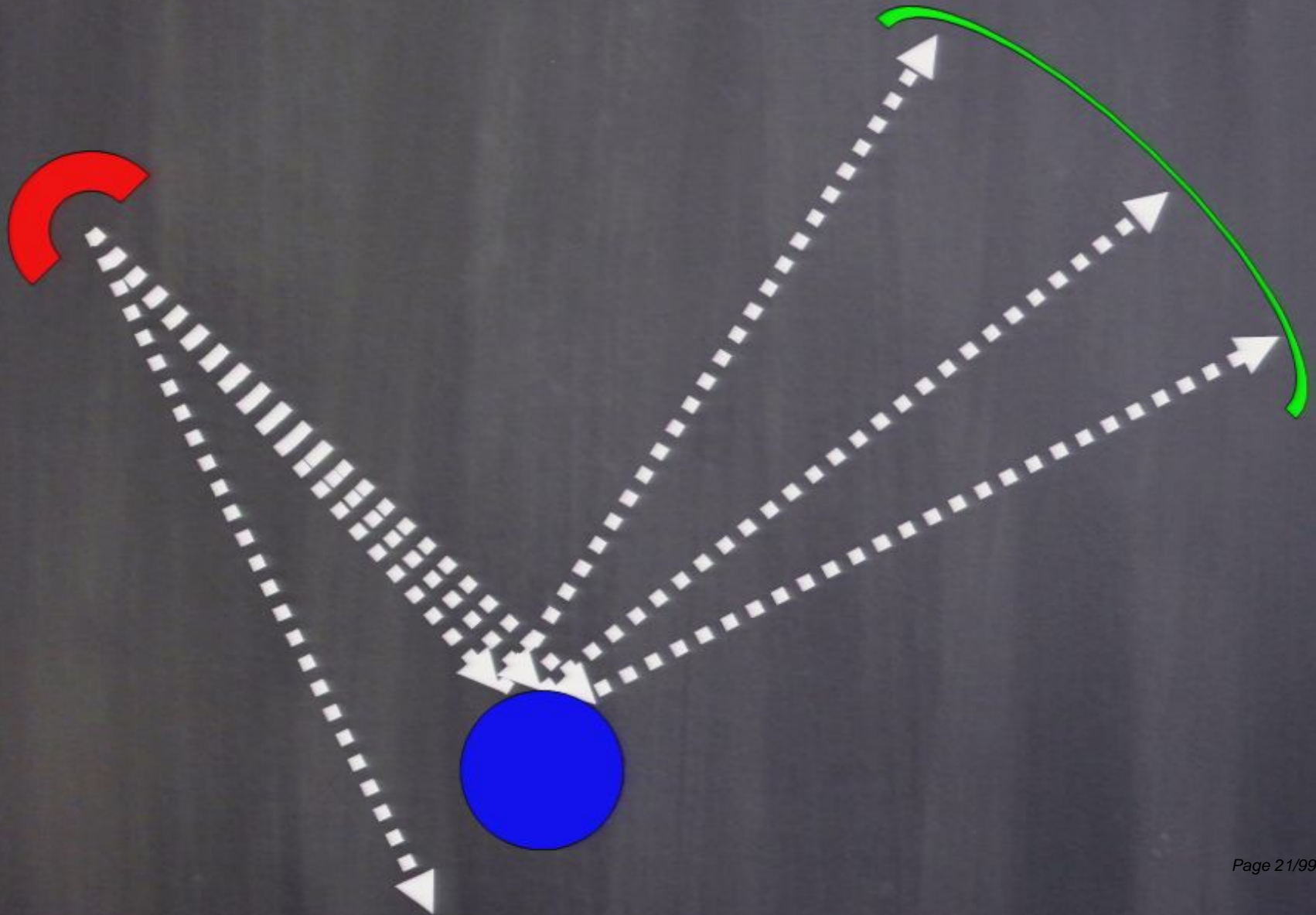
Simplify: Only **ONE** Atom



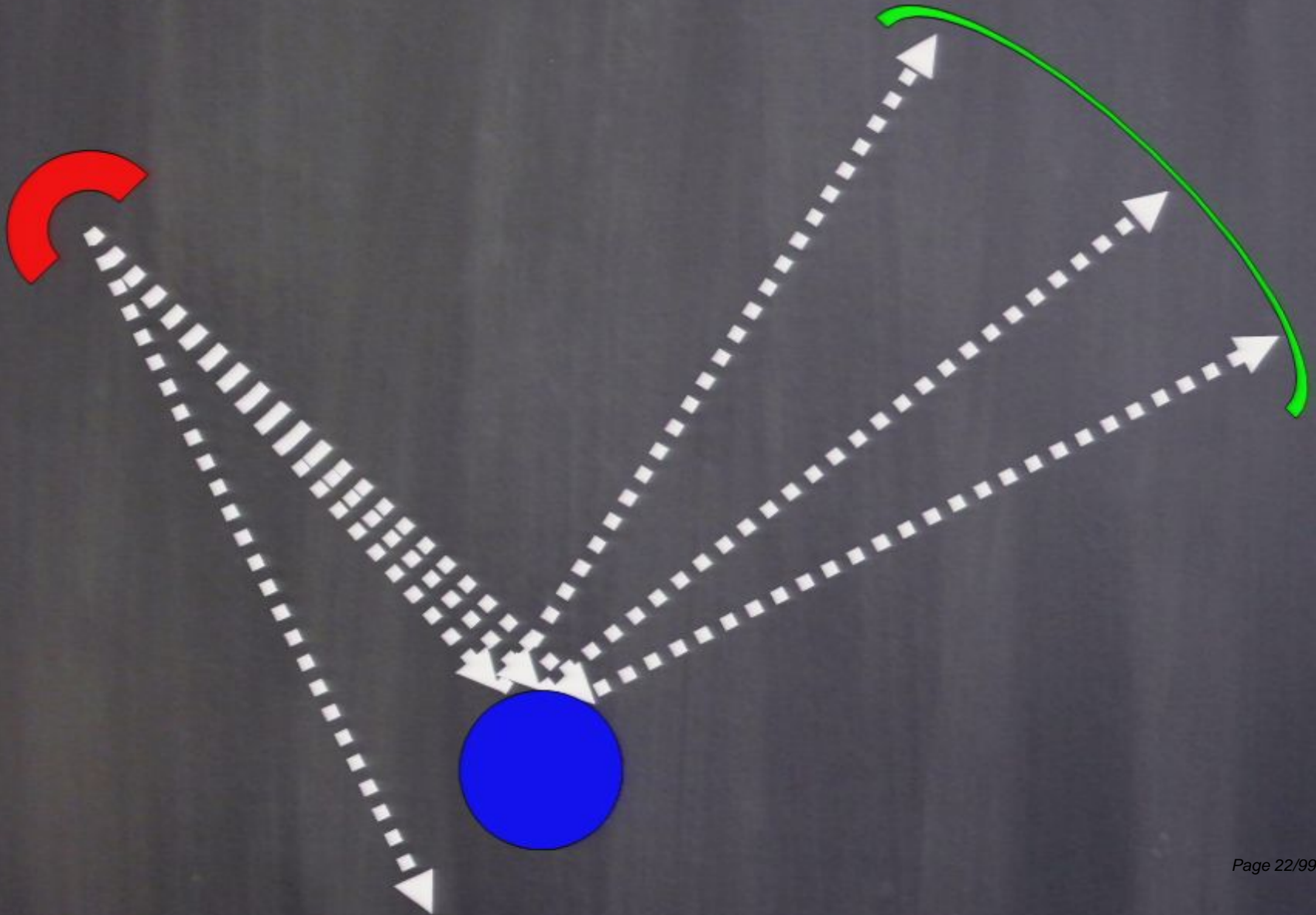
Simplify: Only **ONE** Atom



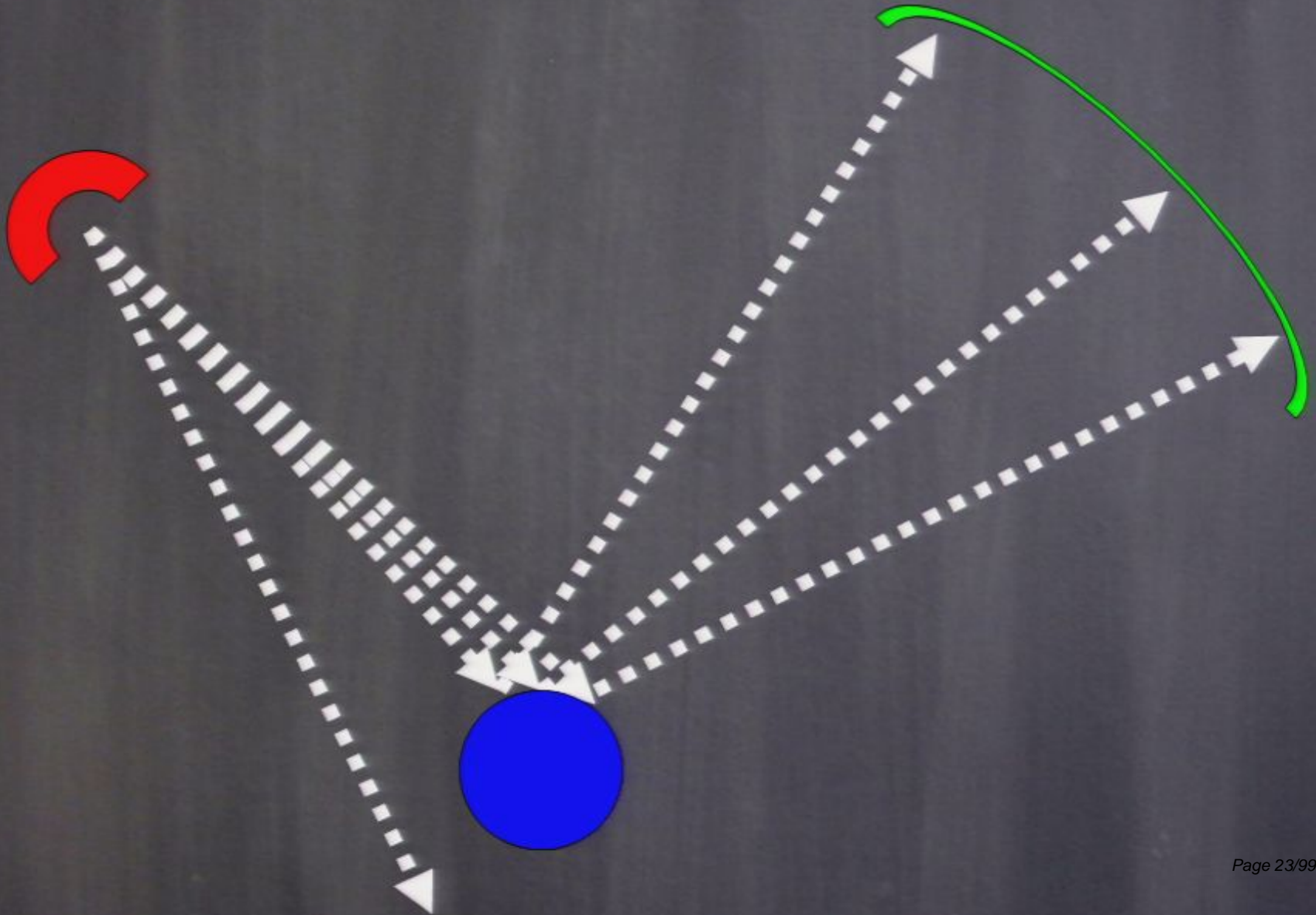
Simplify: Only **ONE** Atom



Expect?



Expect?



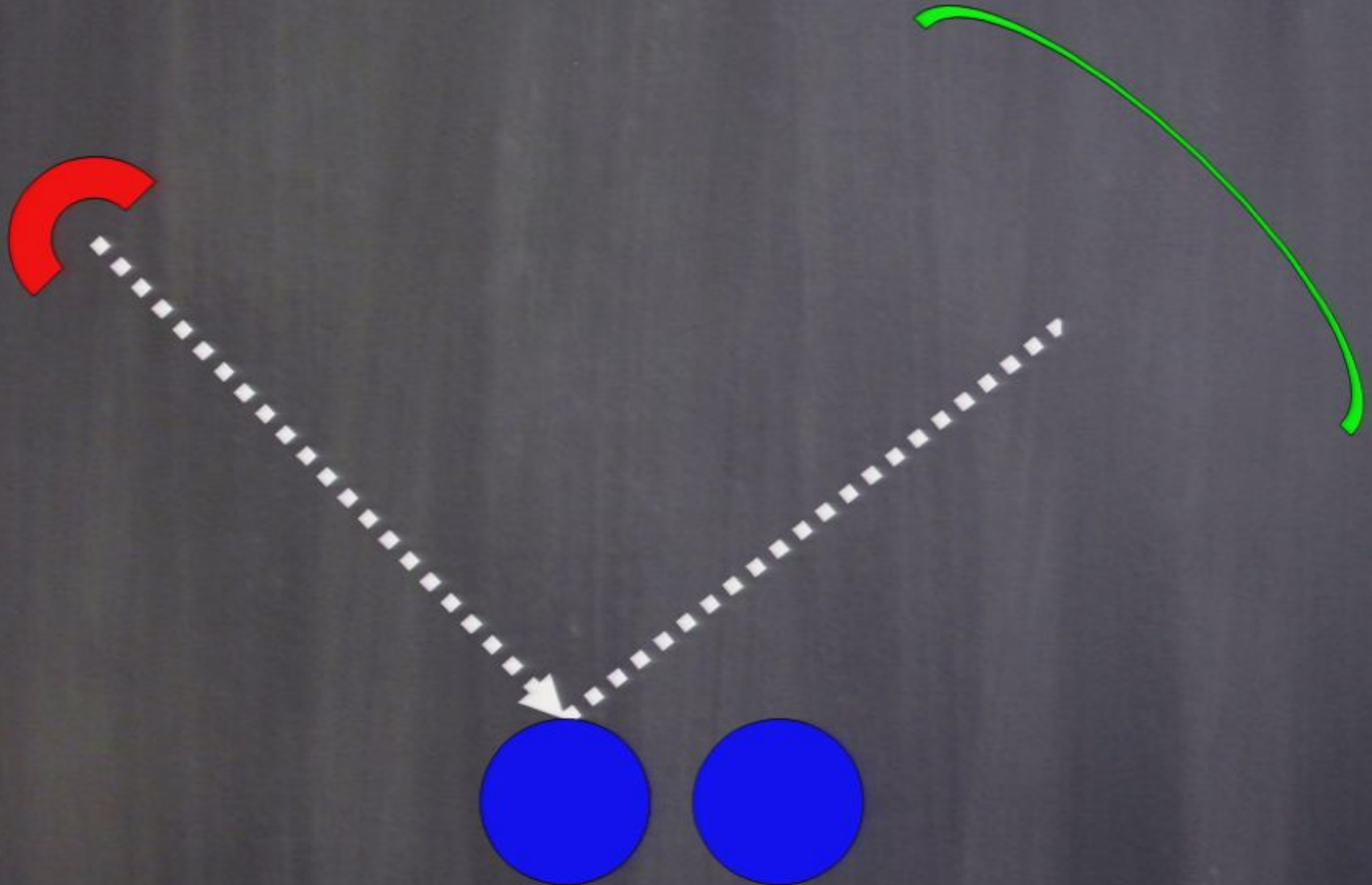
Bring in a **SECOND** Atom



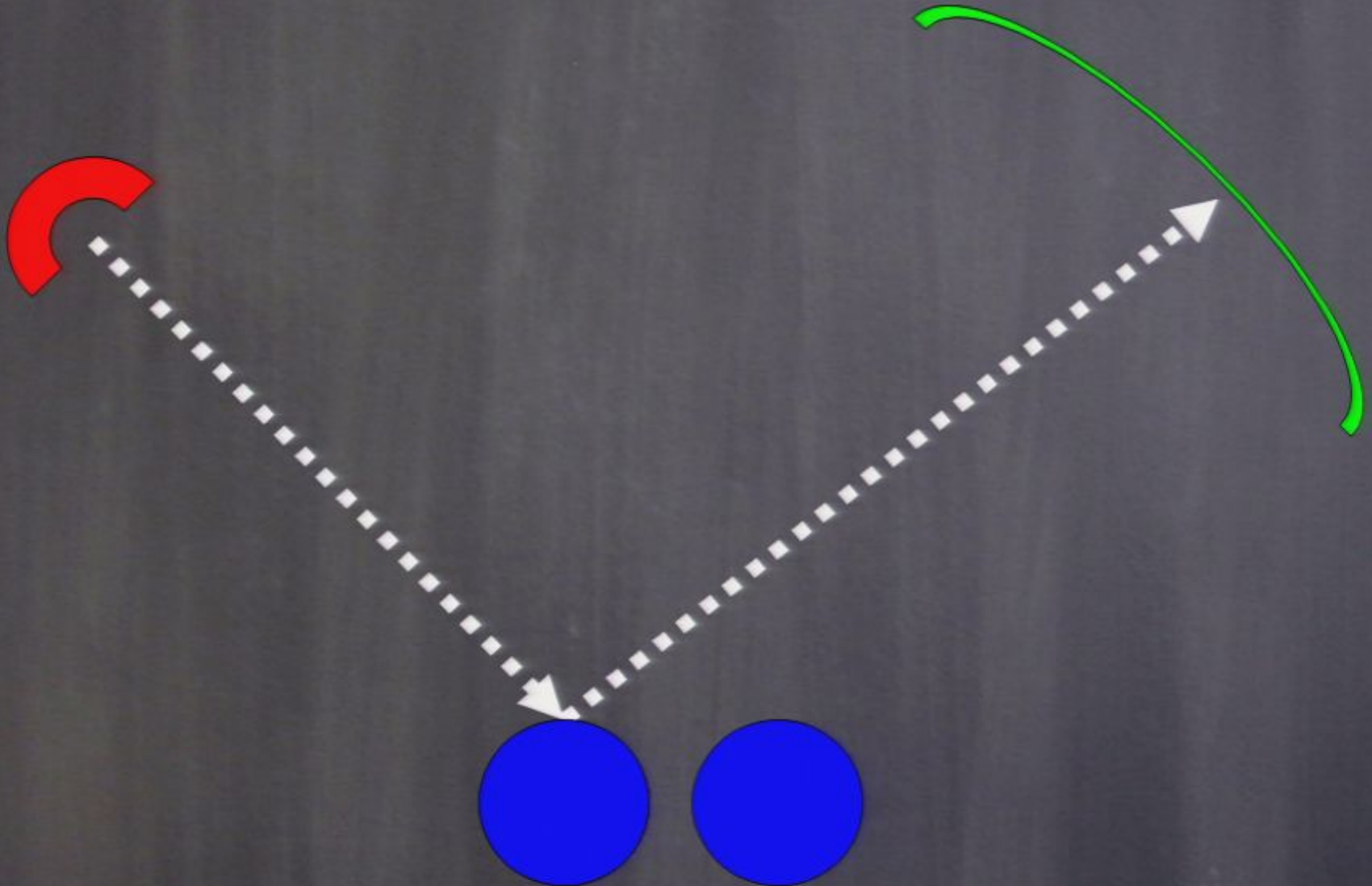
Bring in a **SECOND** Atom



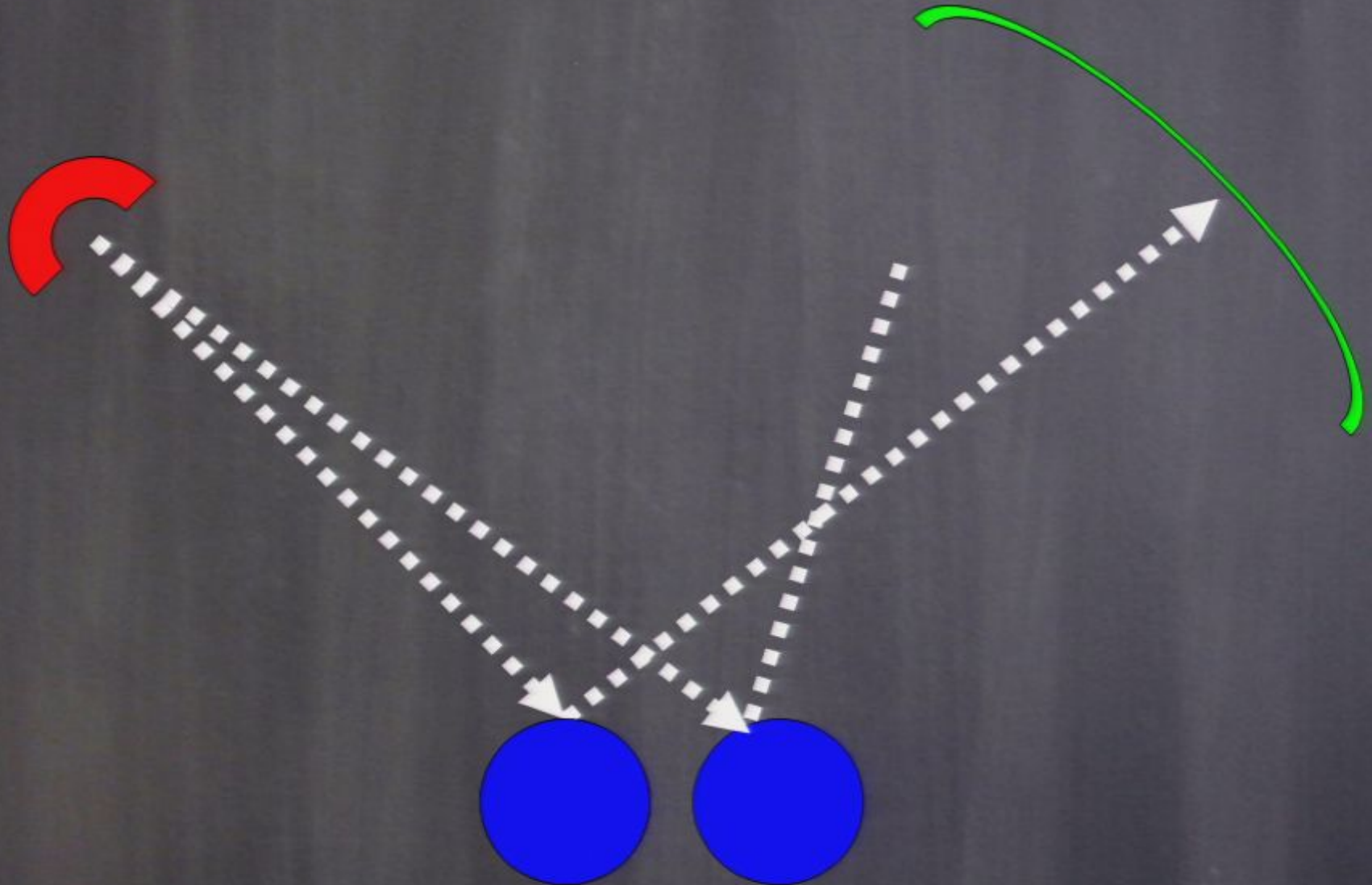
Bring in a **SECOND** Atom



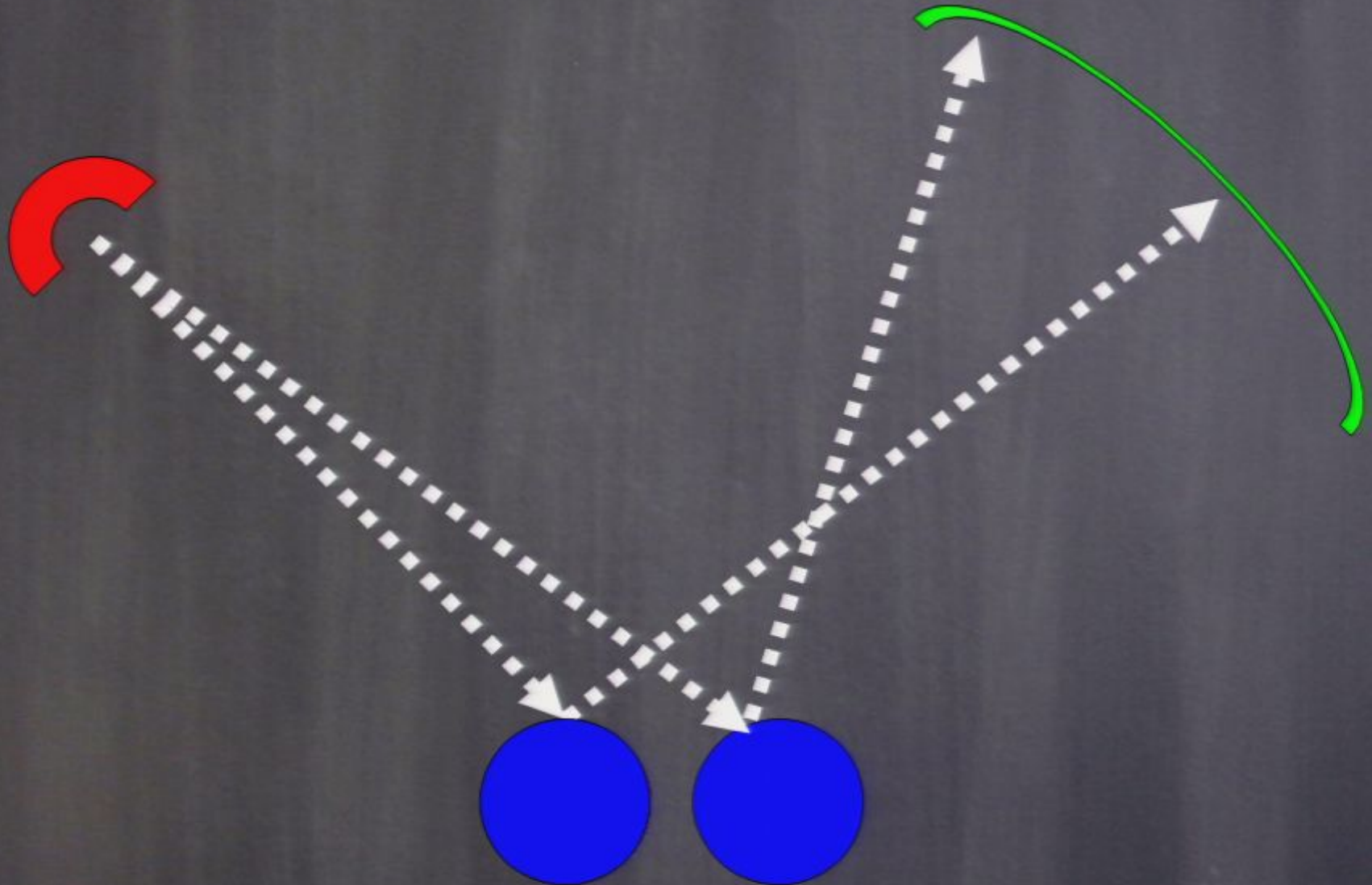
Bring in a **SECOND** Atom



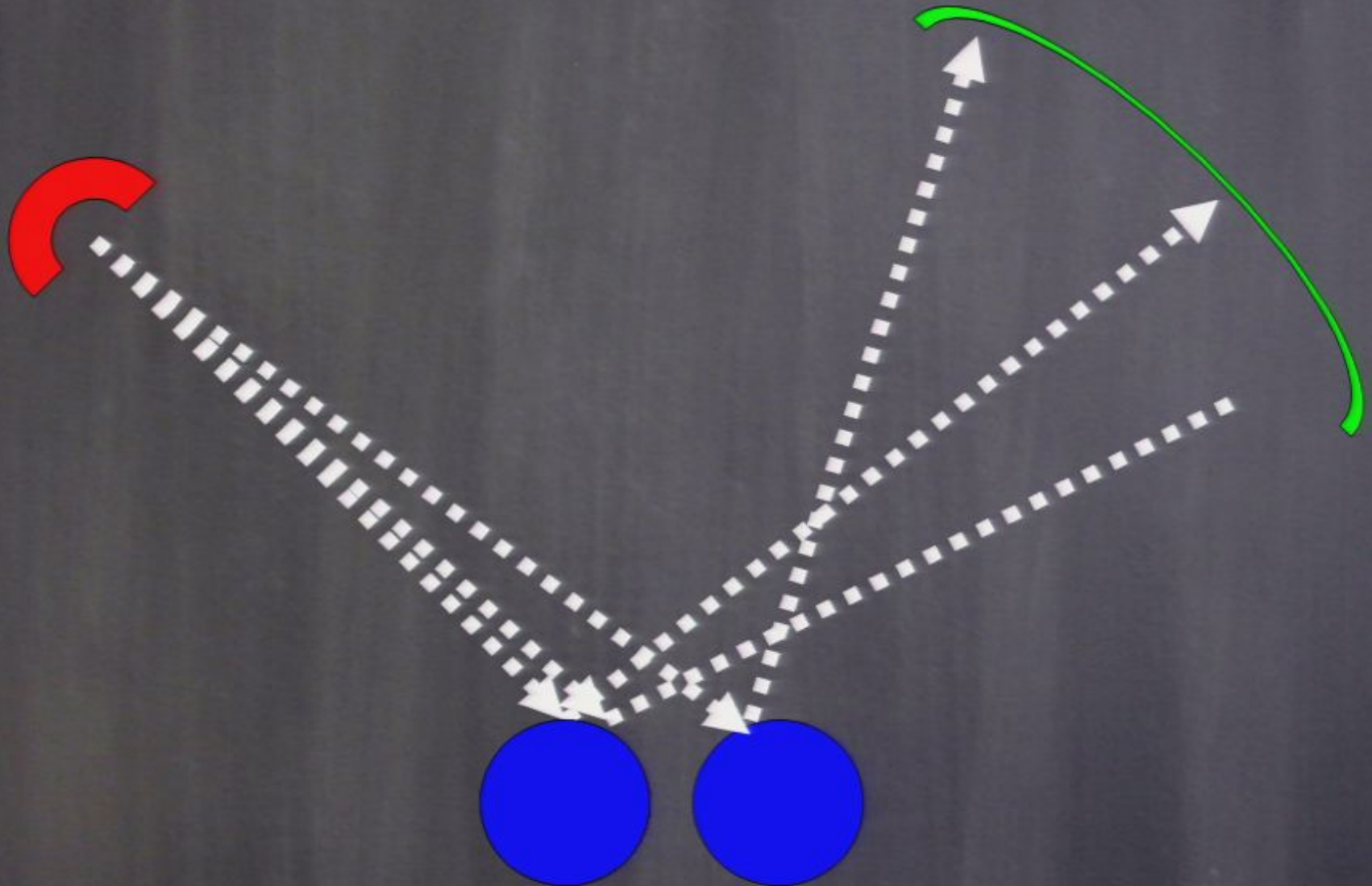
Bring in a **SECOND** Atom



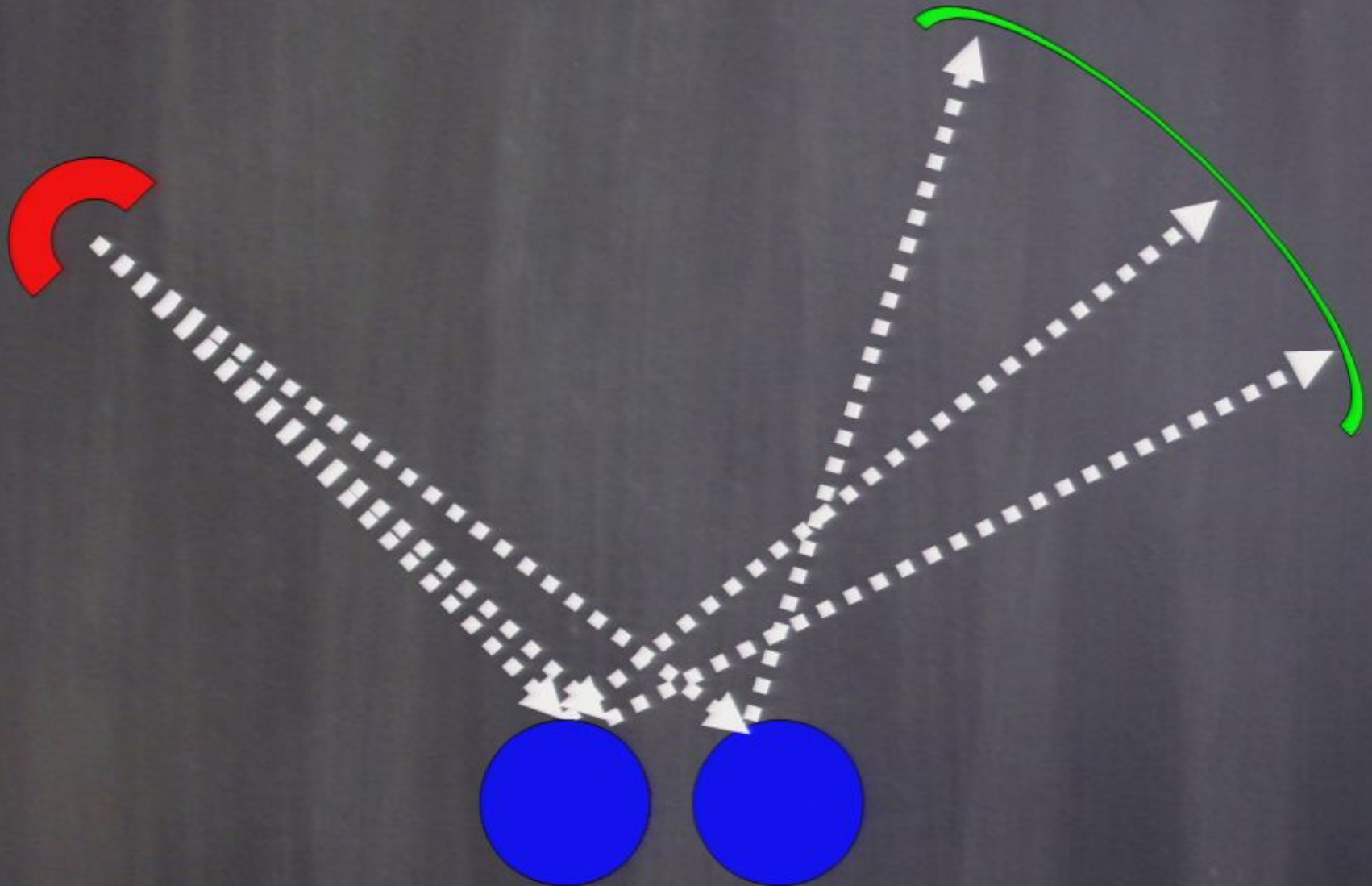
Bring in a **SECOND** Atom



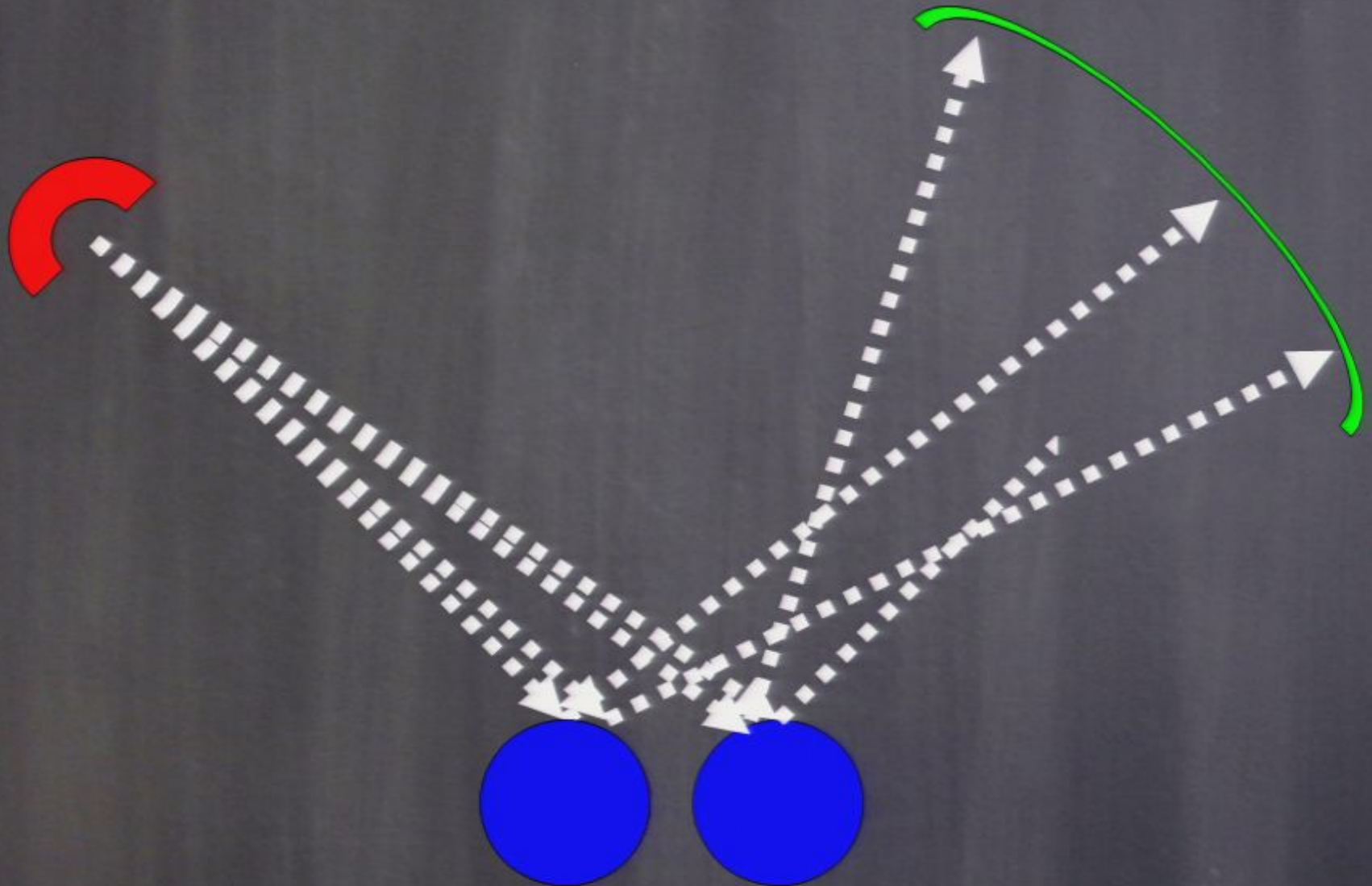
Bring in a **SECOND** Atom



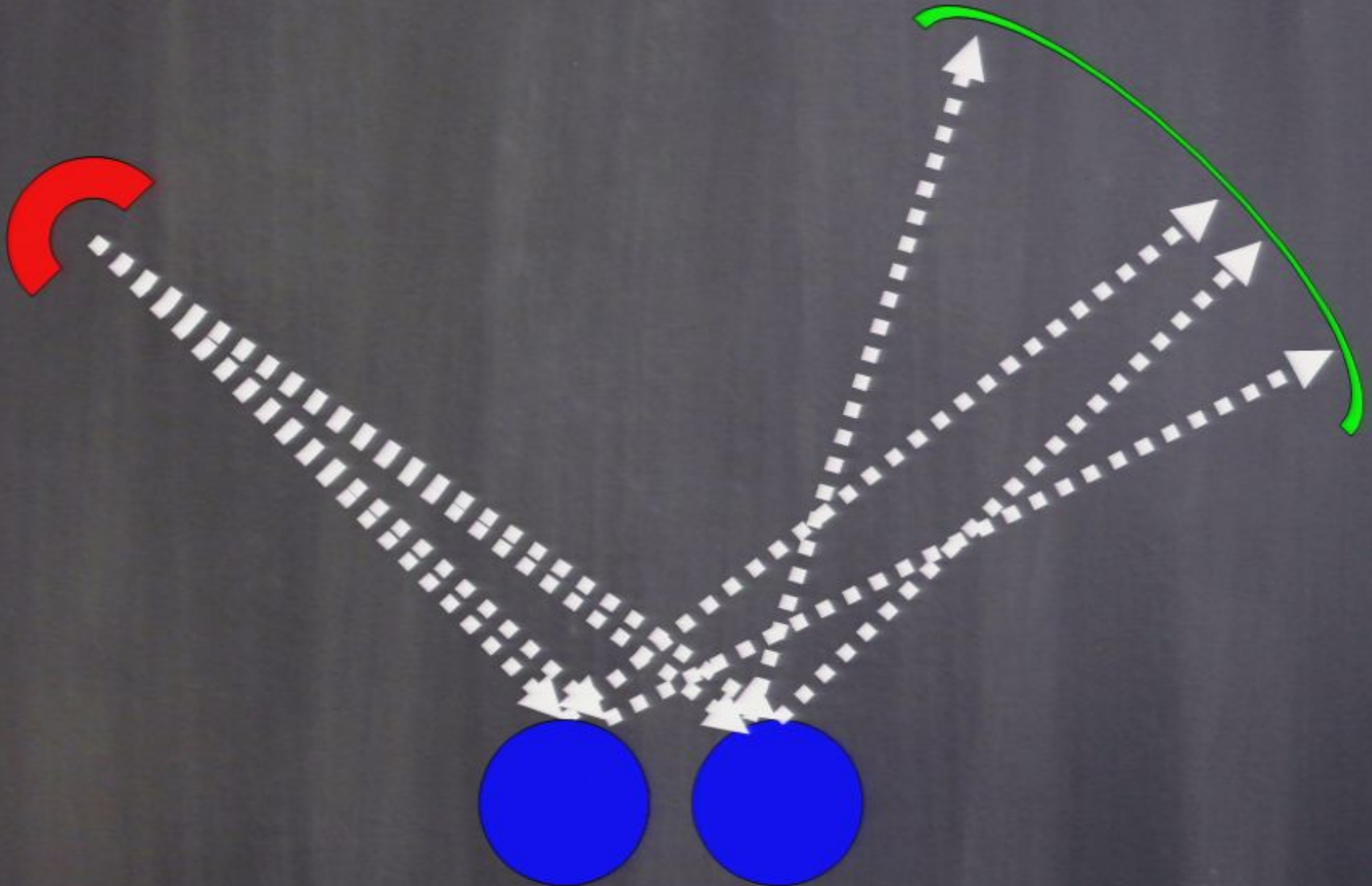
Bring in a **SECOND** Atom



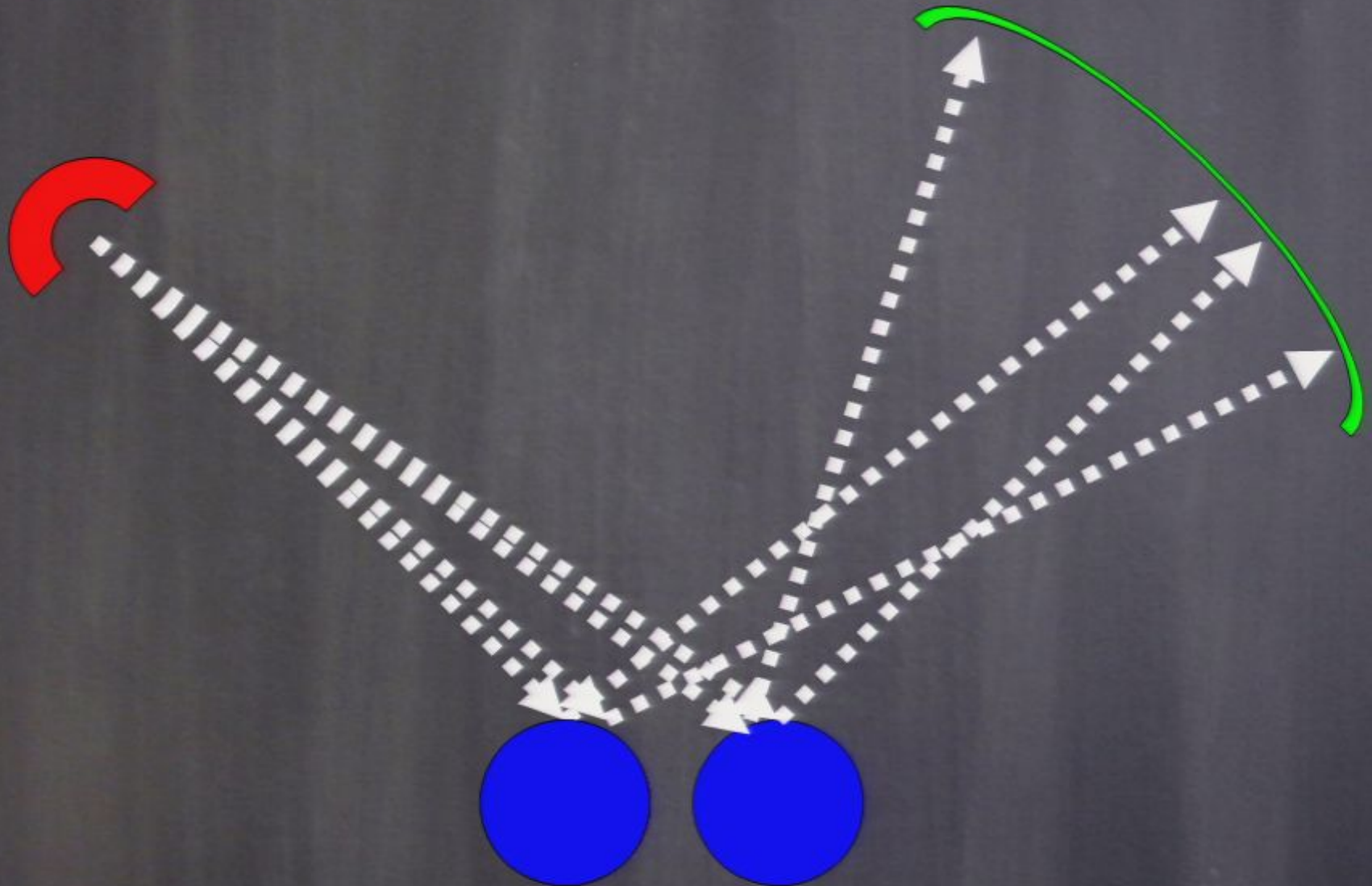
Bring in a **SECOND** Atom



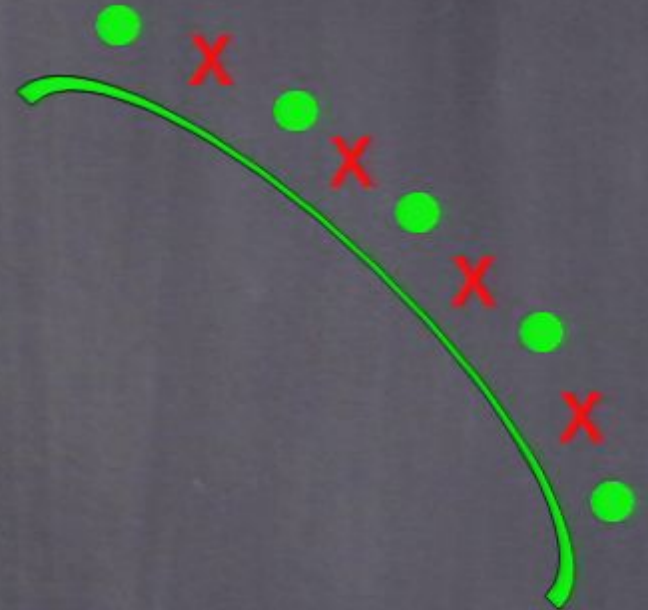
Expect?



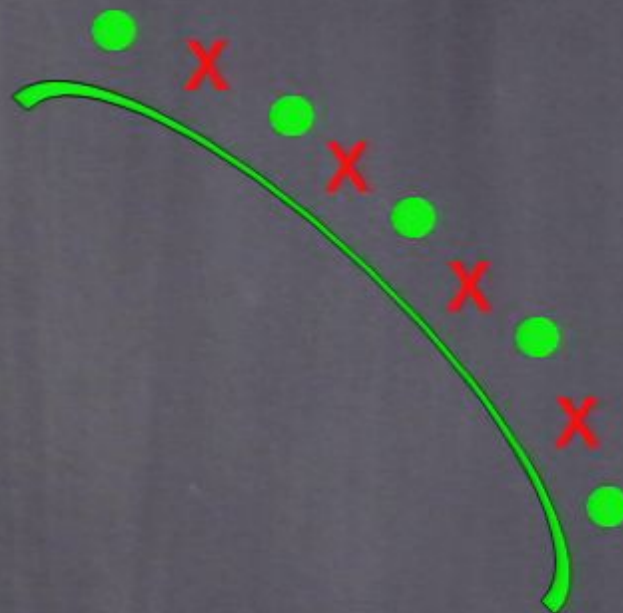
Actual: Pattern of Hits!



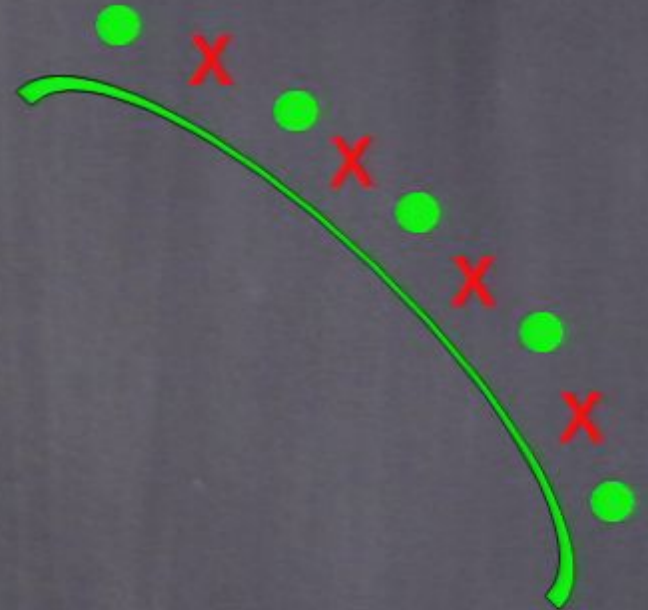
Actual: Pattern of Hits!



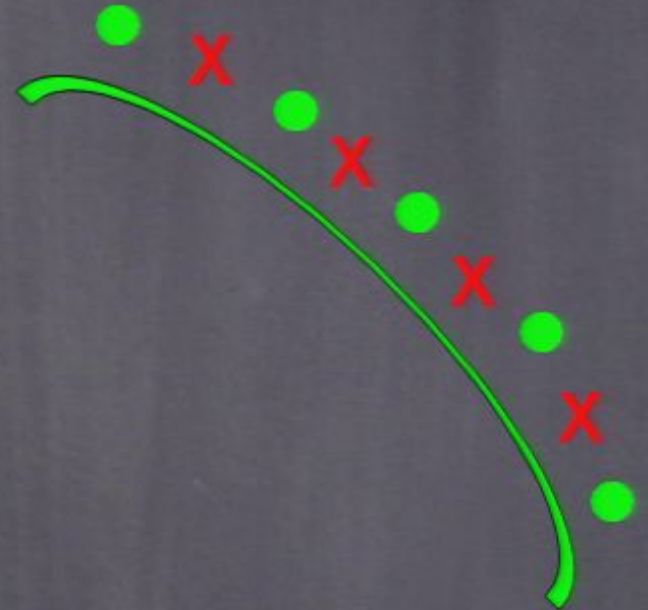
How is this POSSIBLE?



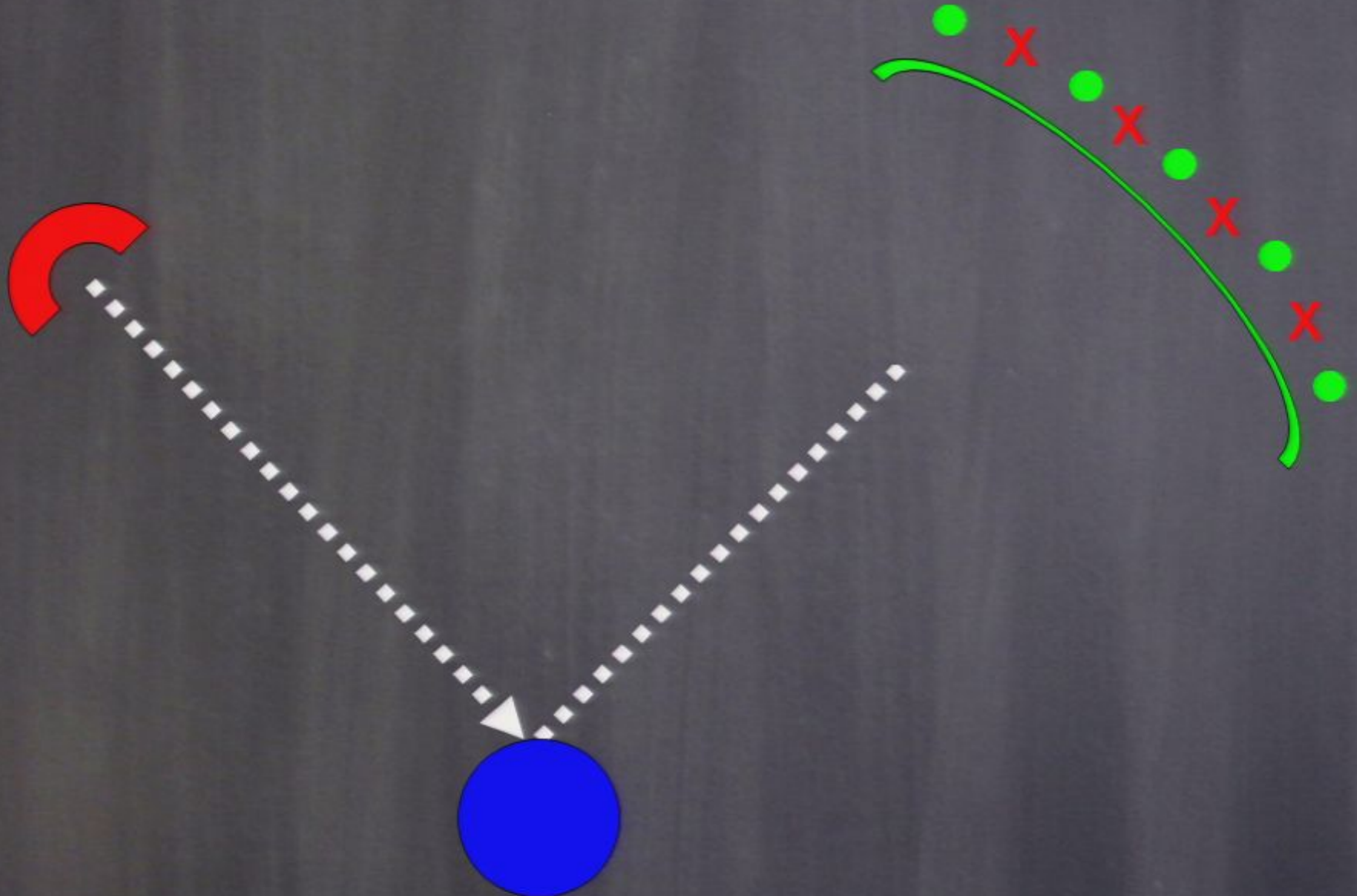
How is this POSSIBLE?



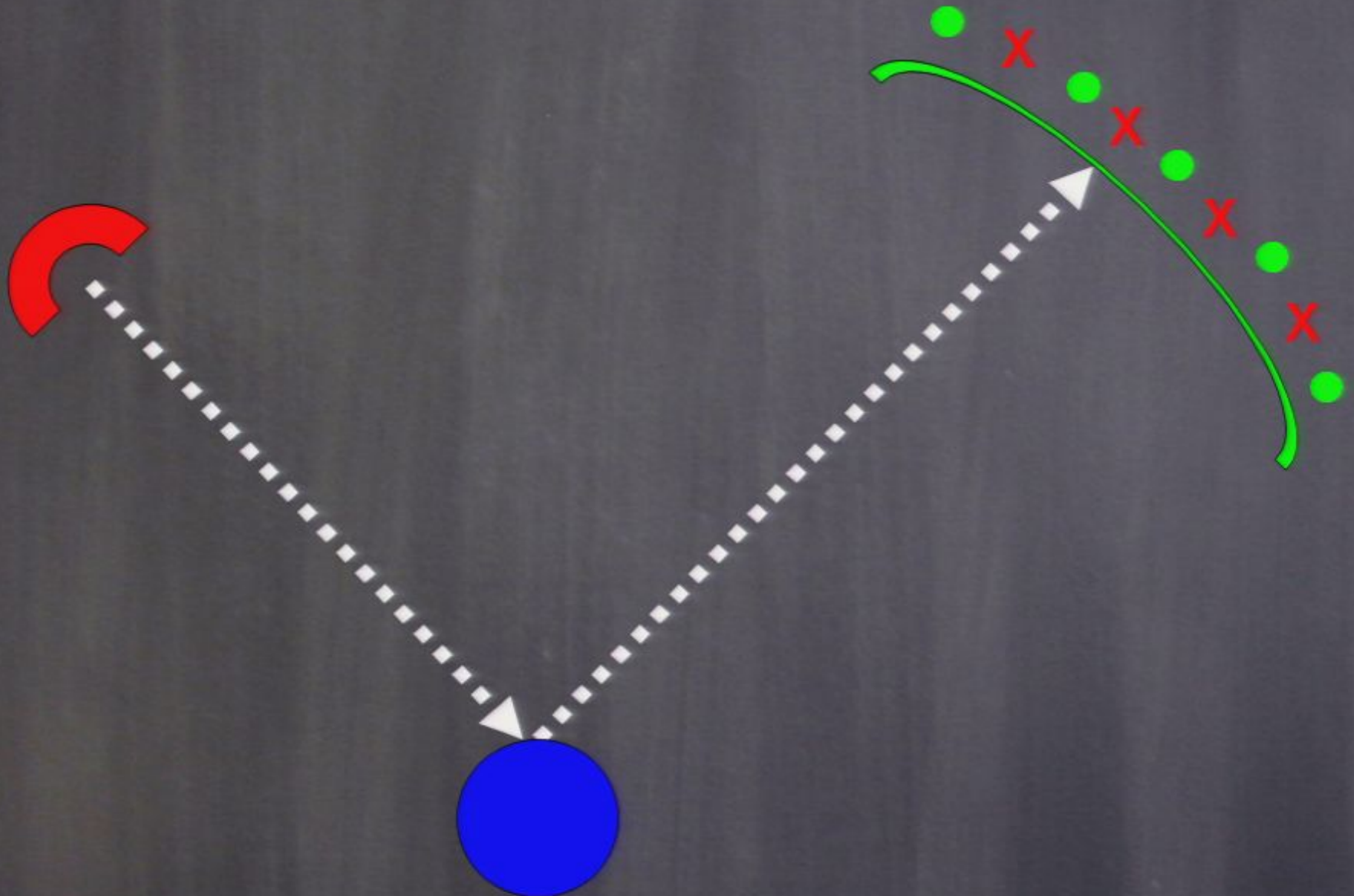
How is this POSSIBLE?



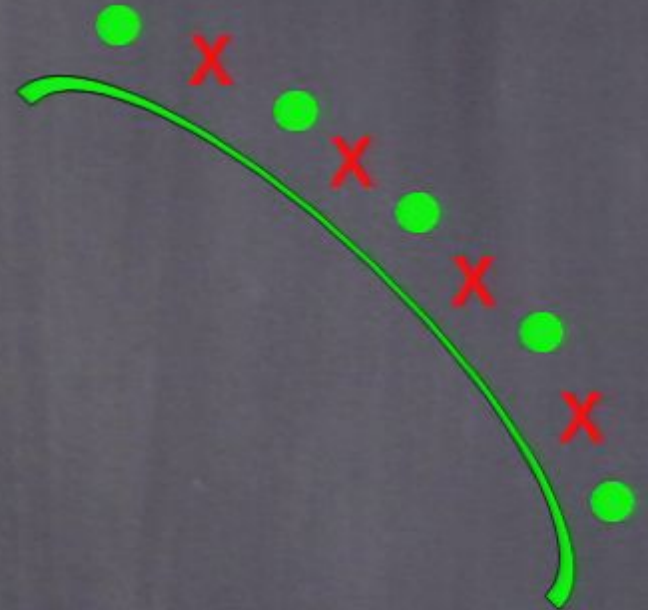
How is this POSSIBLE?



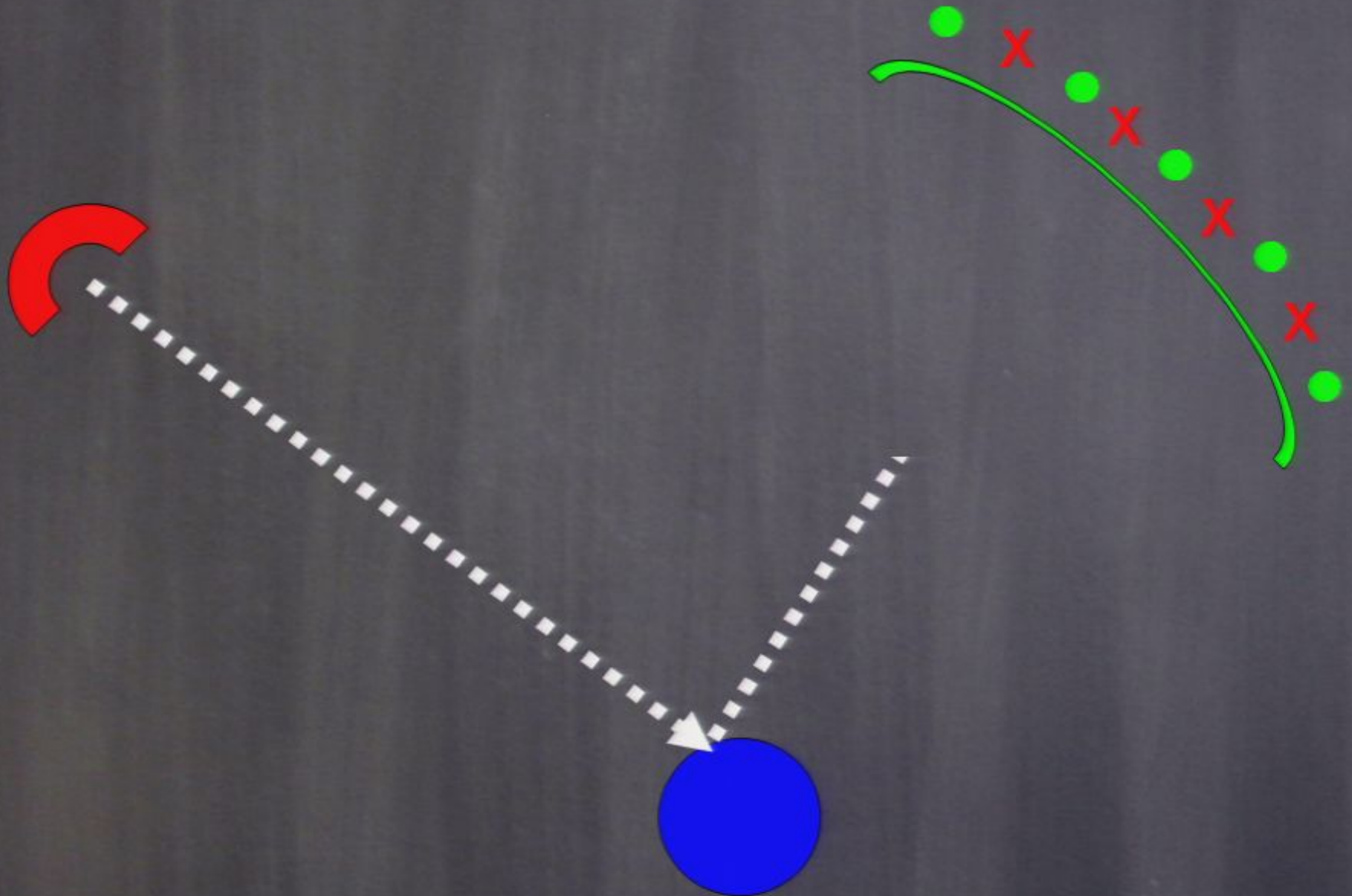
How is this **POSSIBLE?**



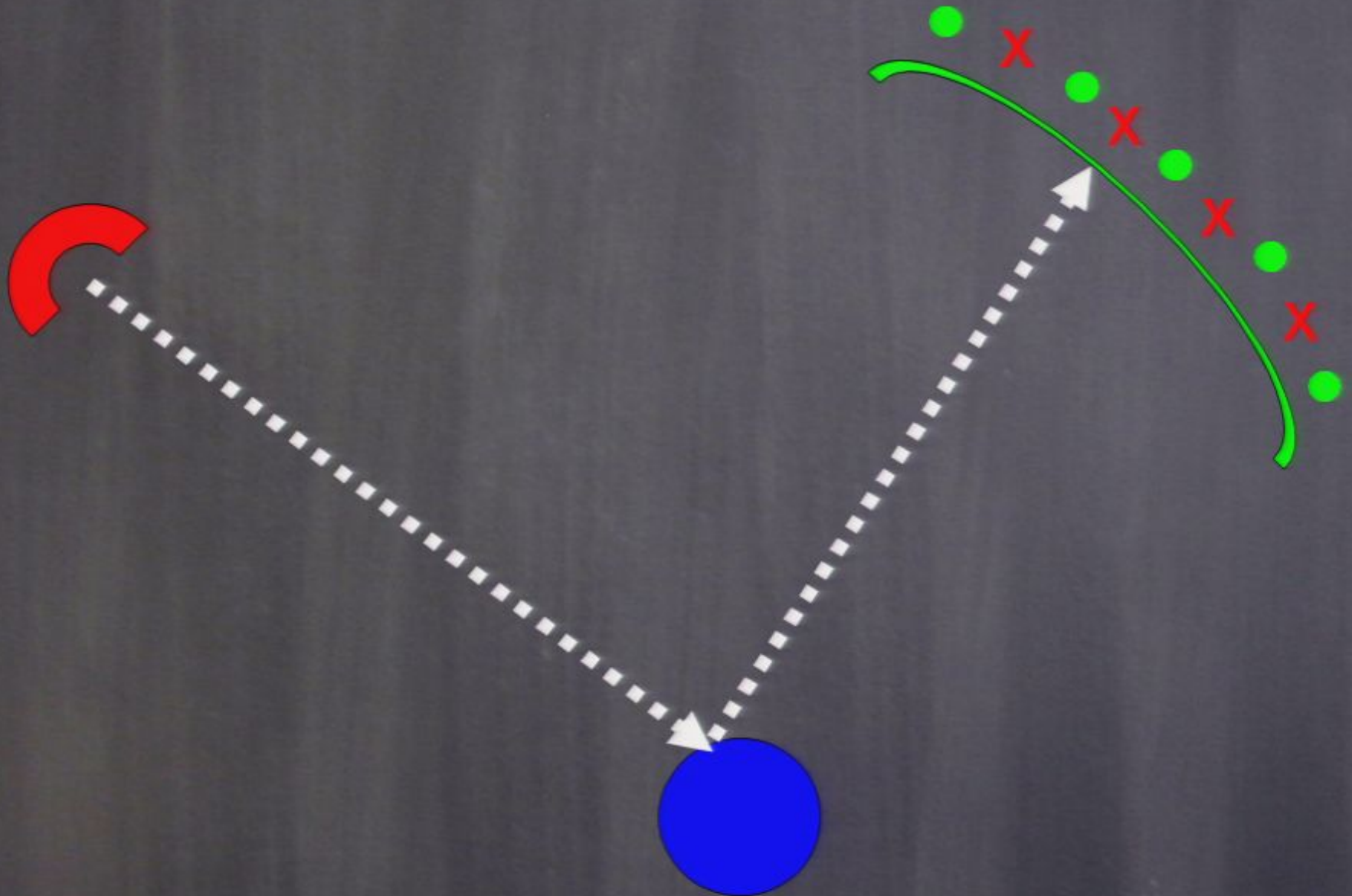
How is this POSSIBLE?



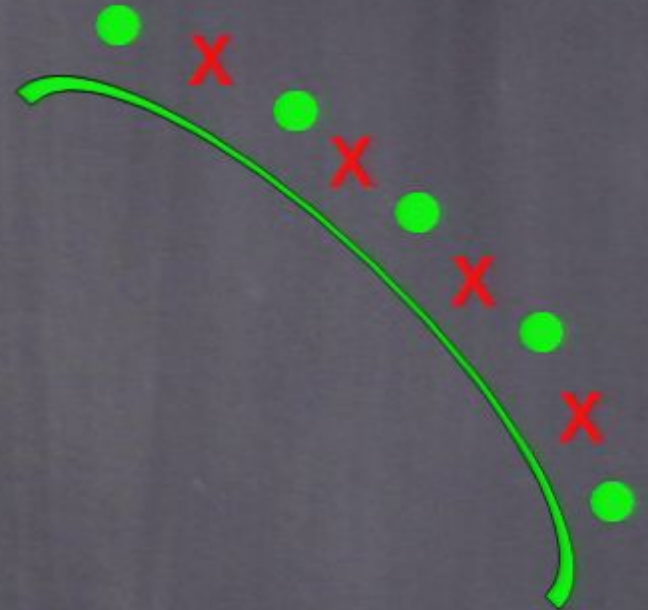
How is this POSSIBLE?



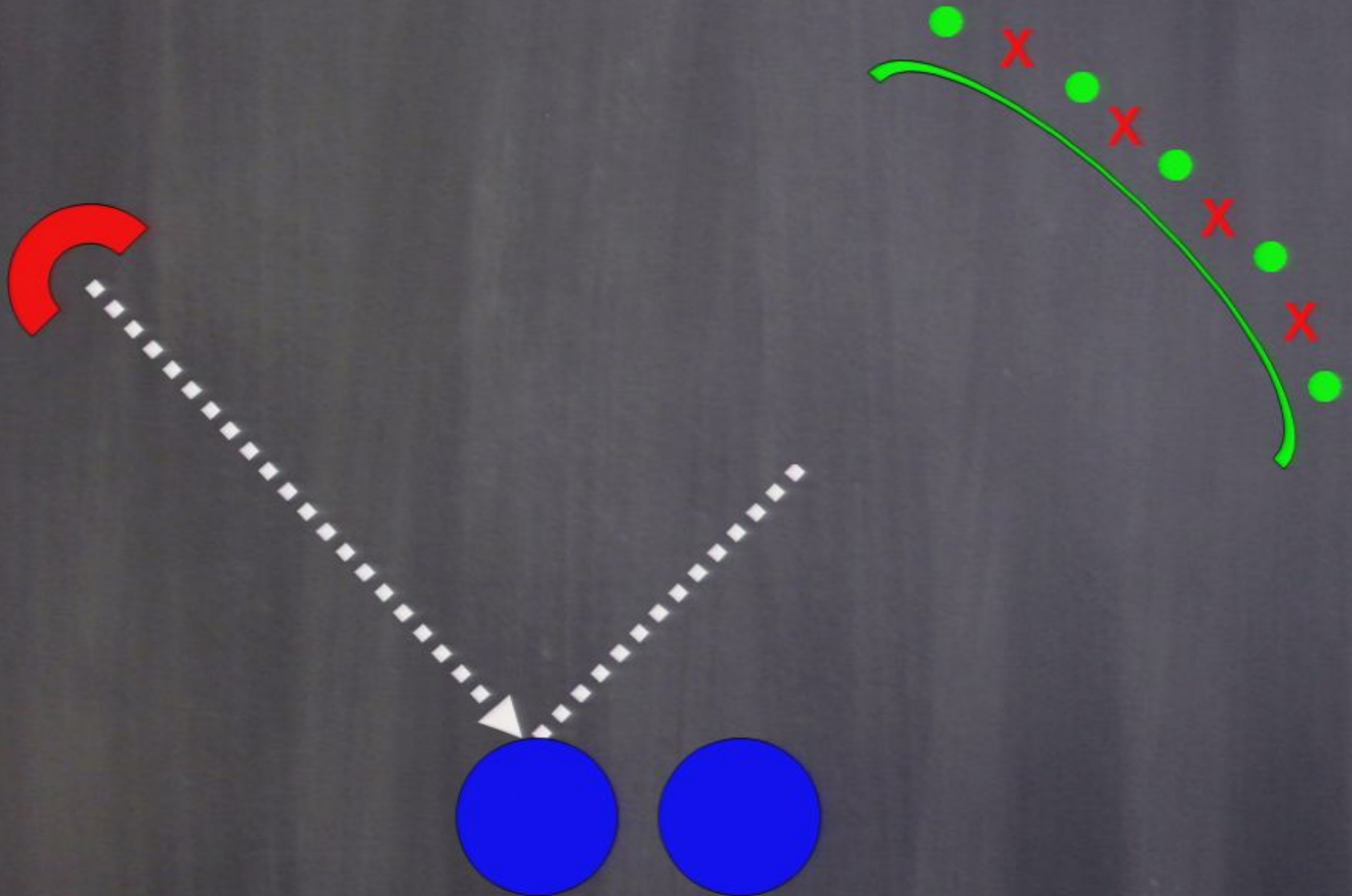
How is this **POSSIBLE?**



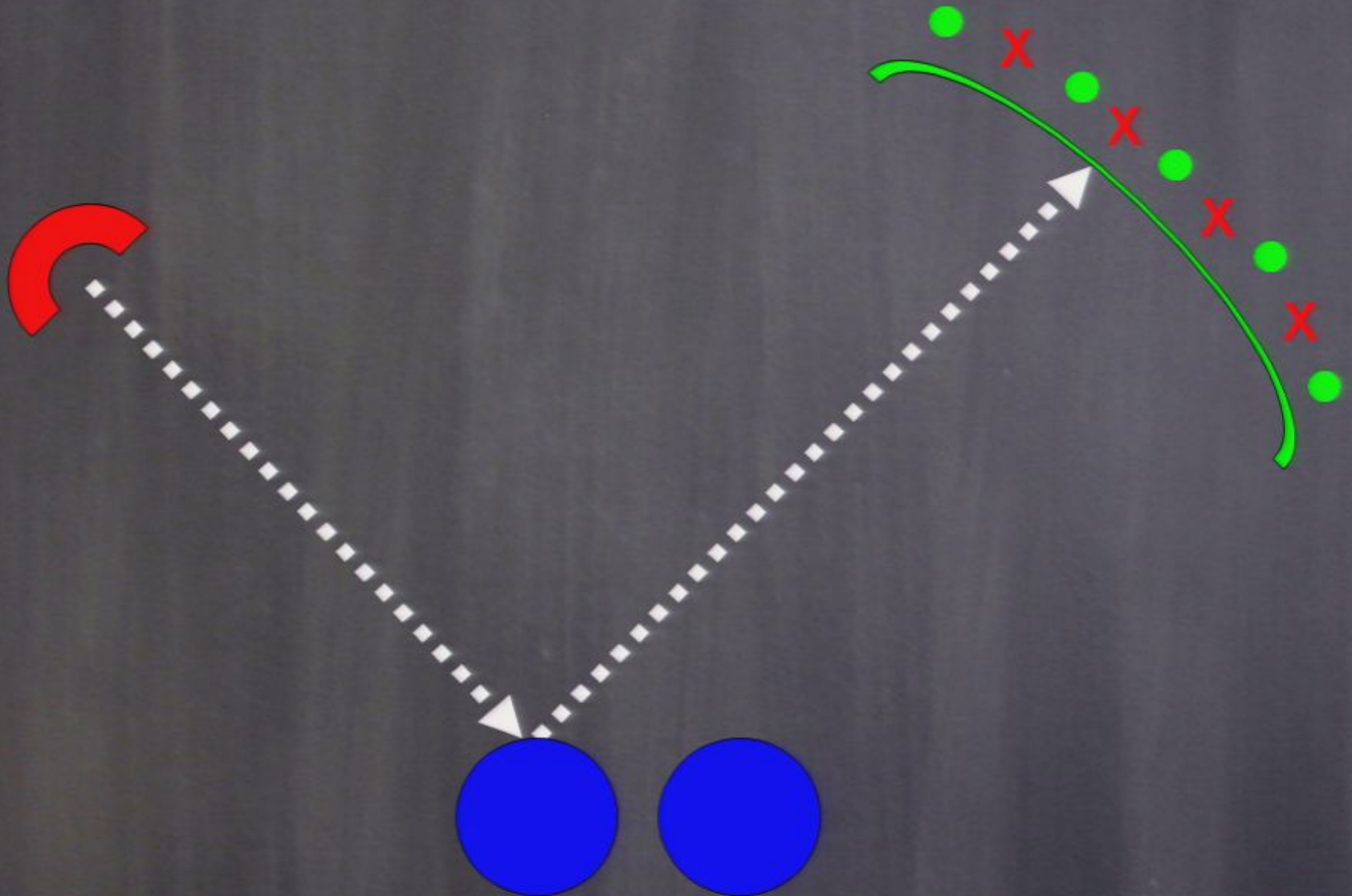
How is this POSSIBLE?



How is this POSSIBLE?

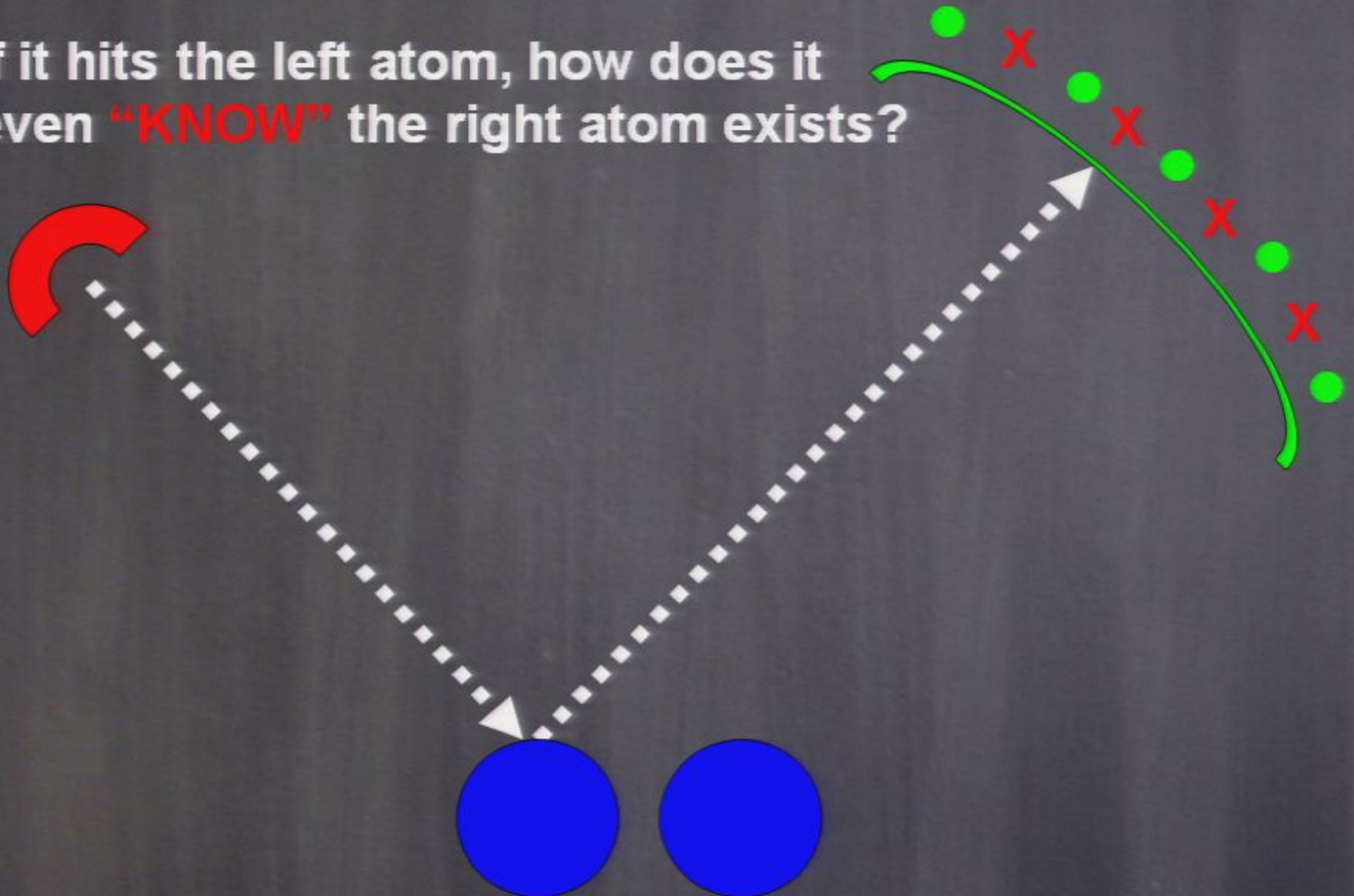


How is this POSSIBLE?

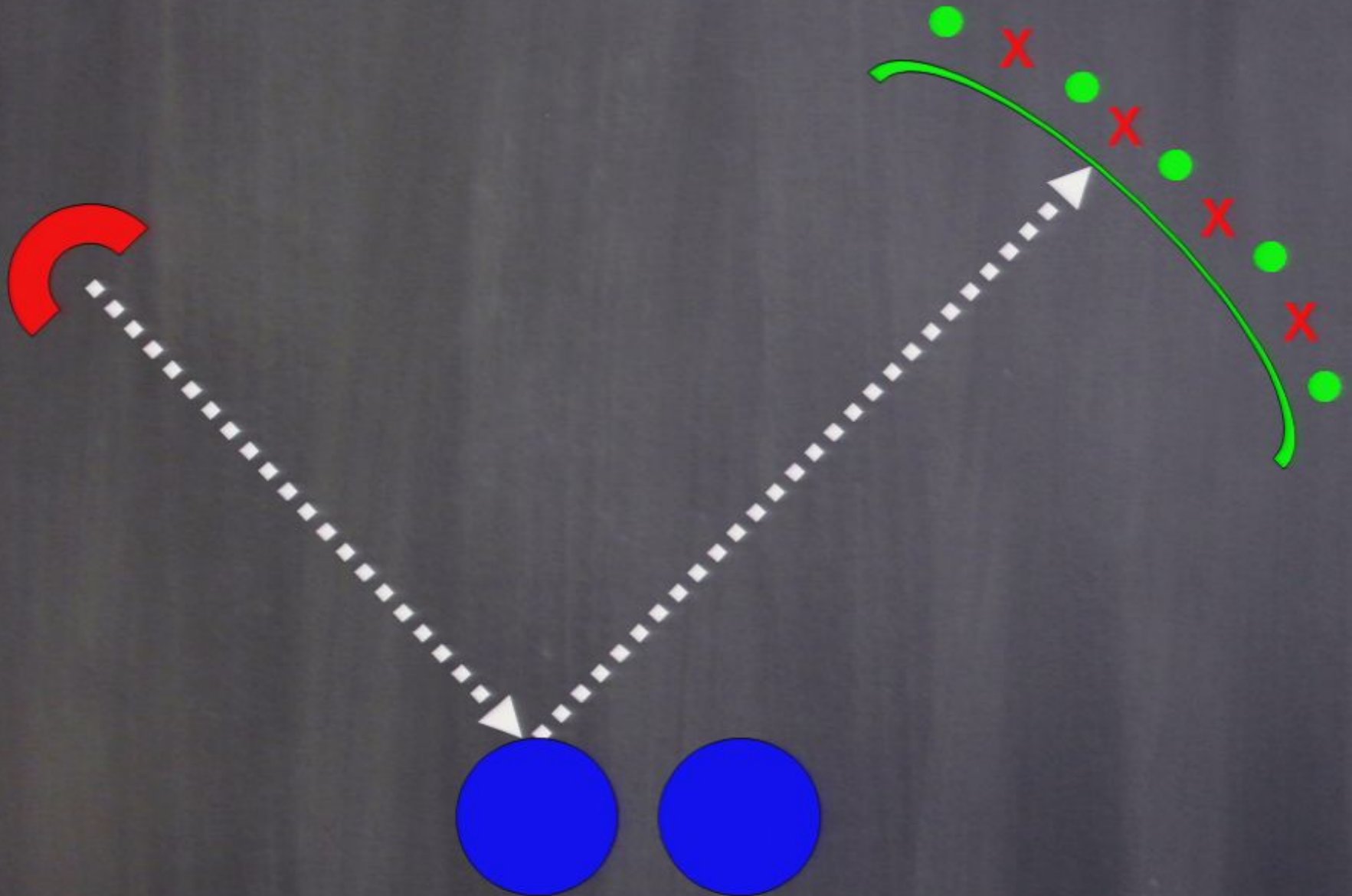


How is this **POSSIBLE**?

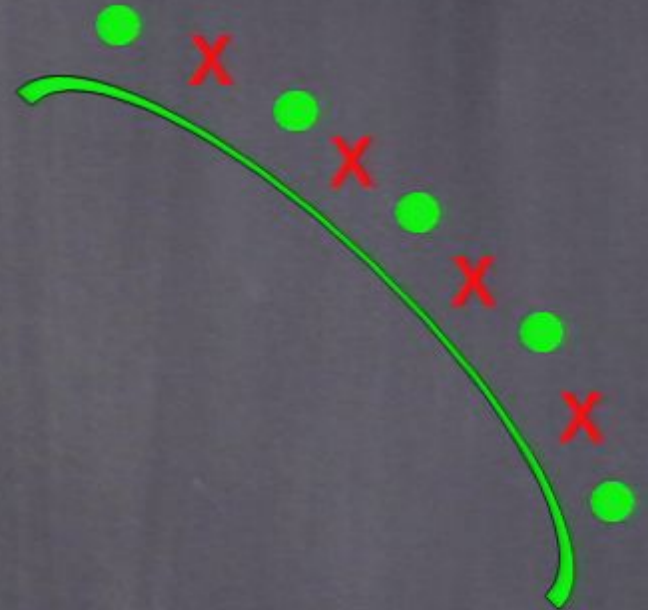
If it hits the left atom, how does it even **“KNOW”** the right atom exists?



How is this **POSSIBLE?**

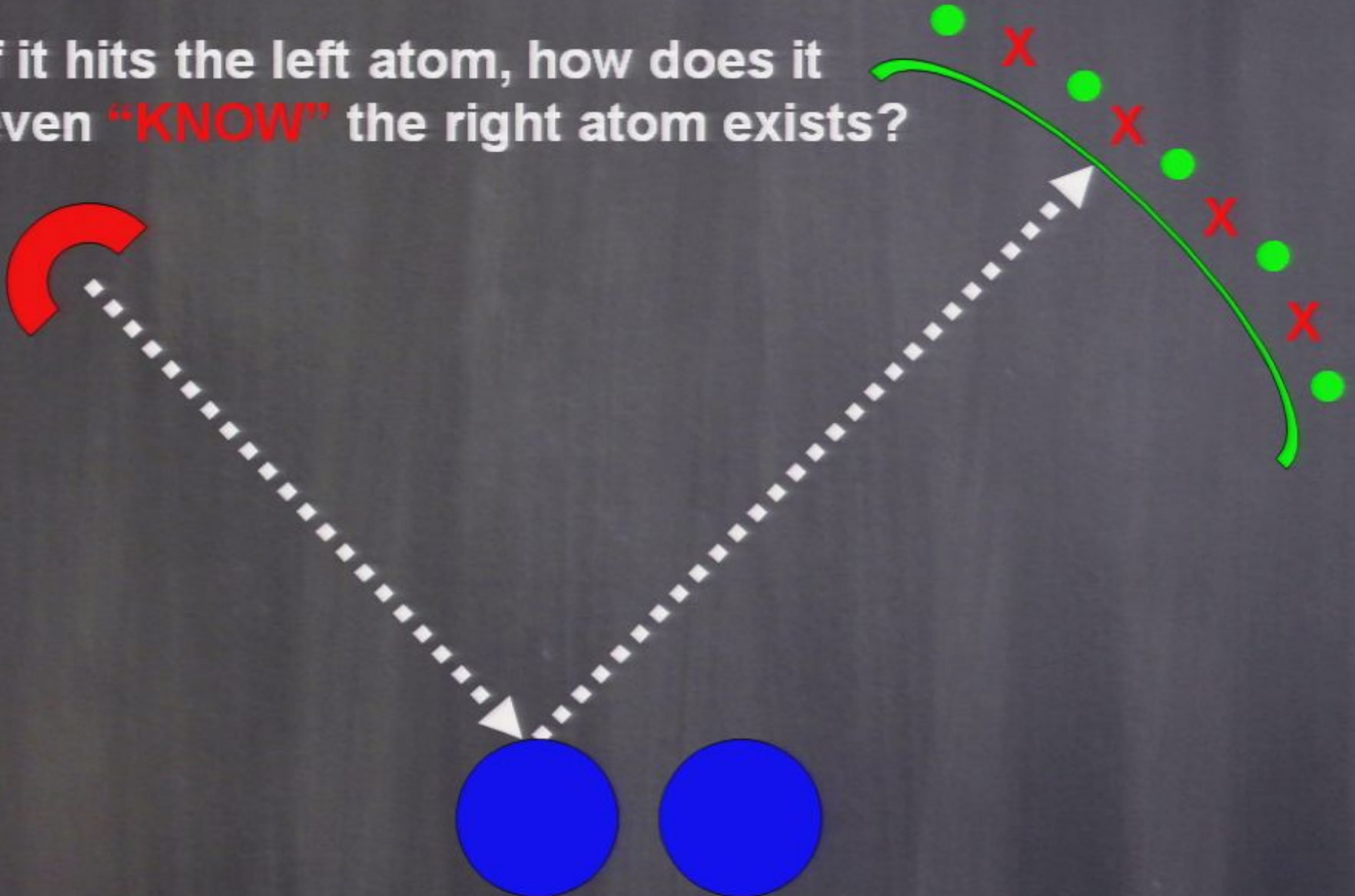


How is this POSSIBLE?



How is this **POSSIBLE**?

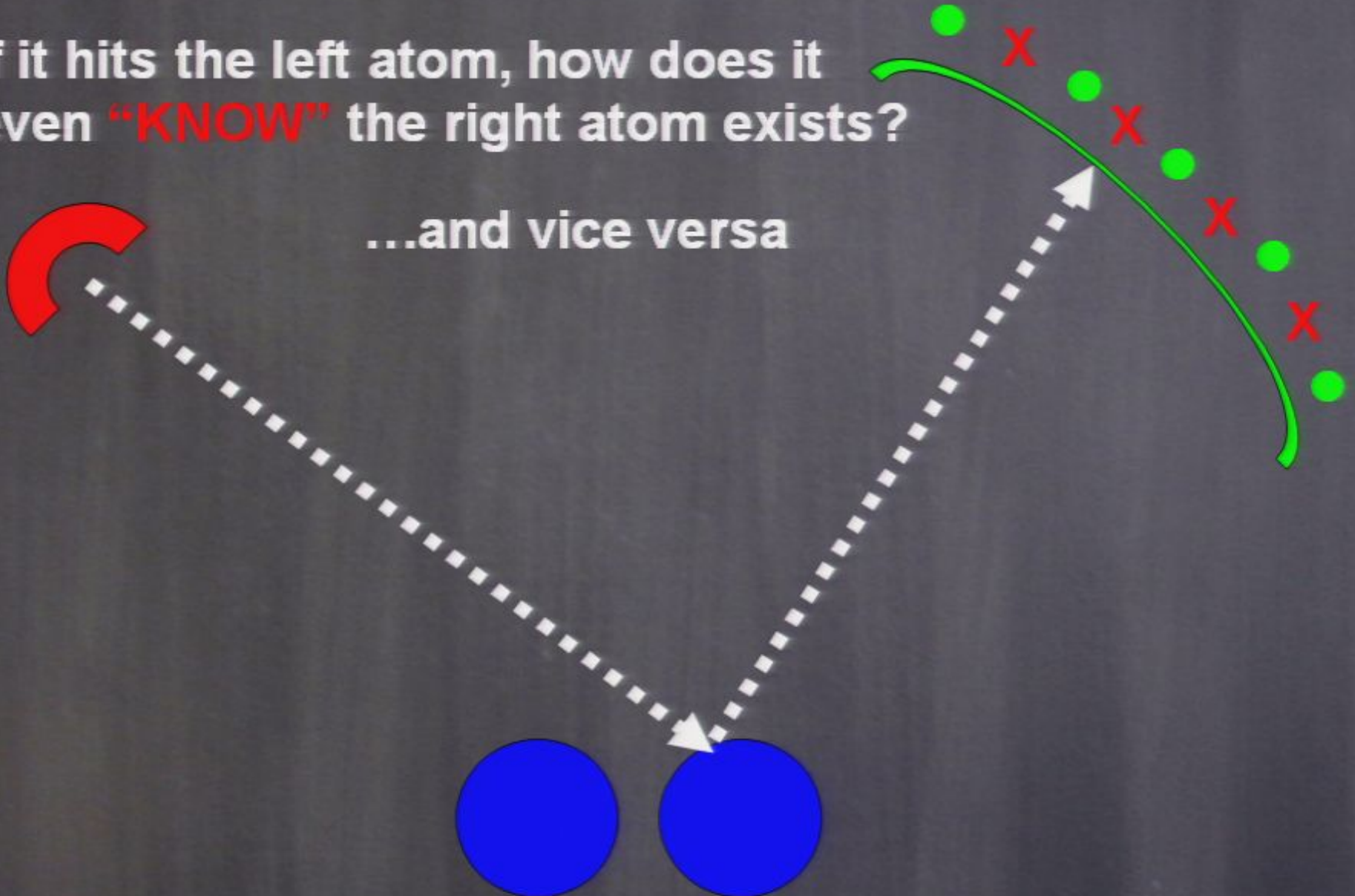
If it hits the left atom, how does it even **“KNOW”** the right atom exists?



How is this **POSSIBLE**?

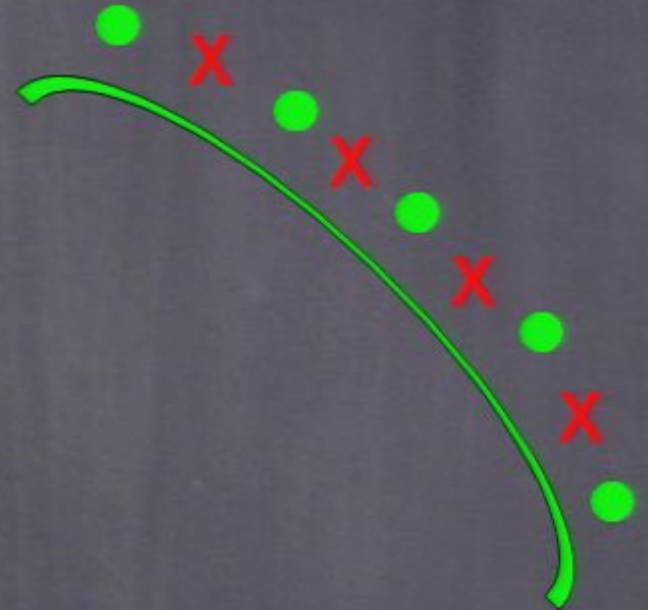
If it hits the left atom, how does it even **“KNOW”** the right atom exists?

...and vice versa



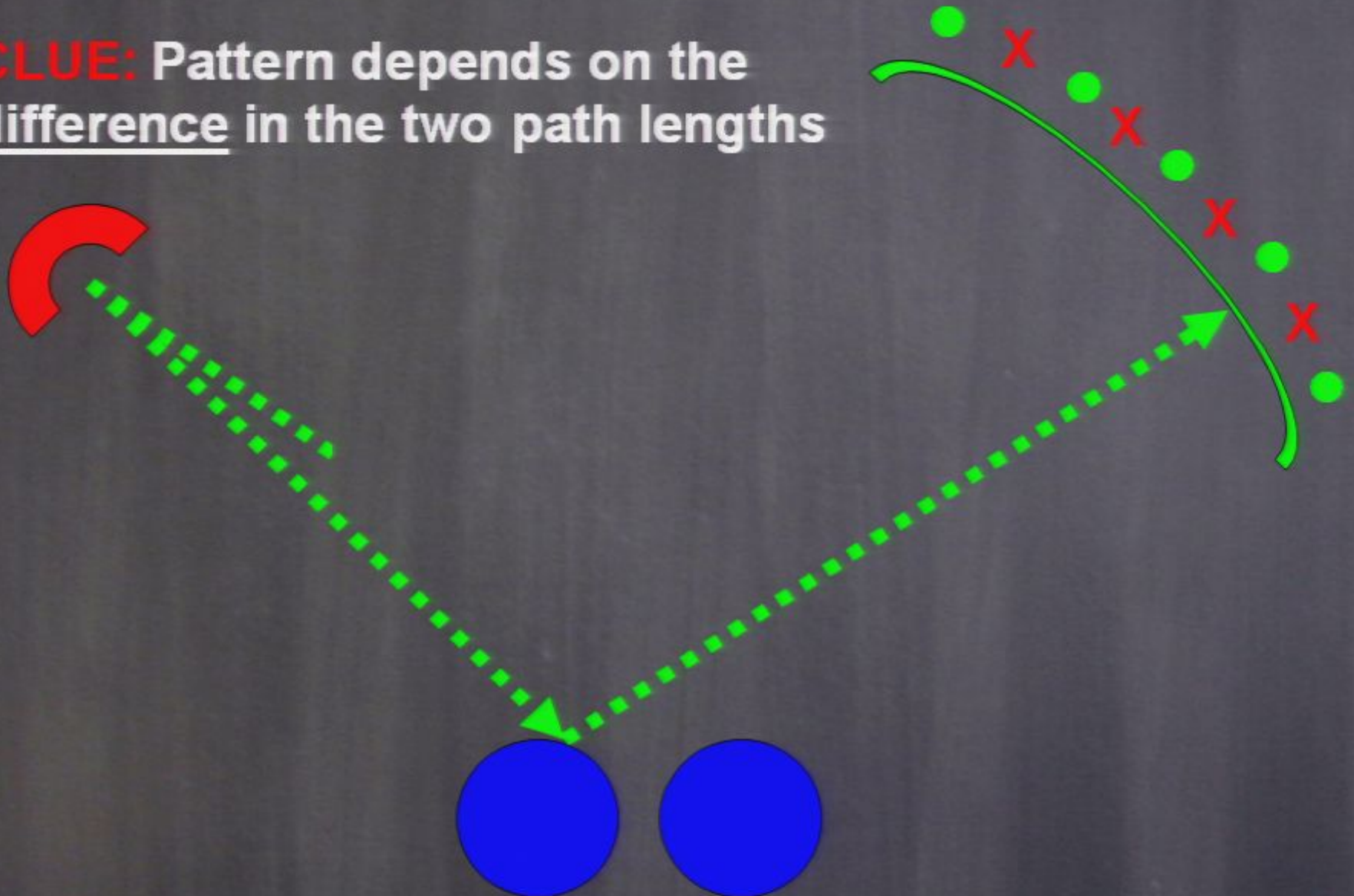
How is this POSSIBLE?

CLUE: Pattern depends on the difference in the two path lengths



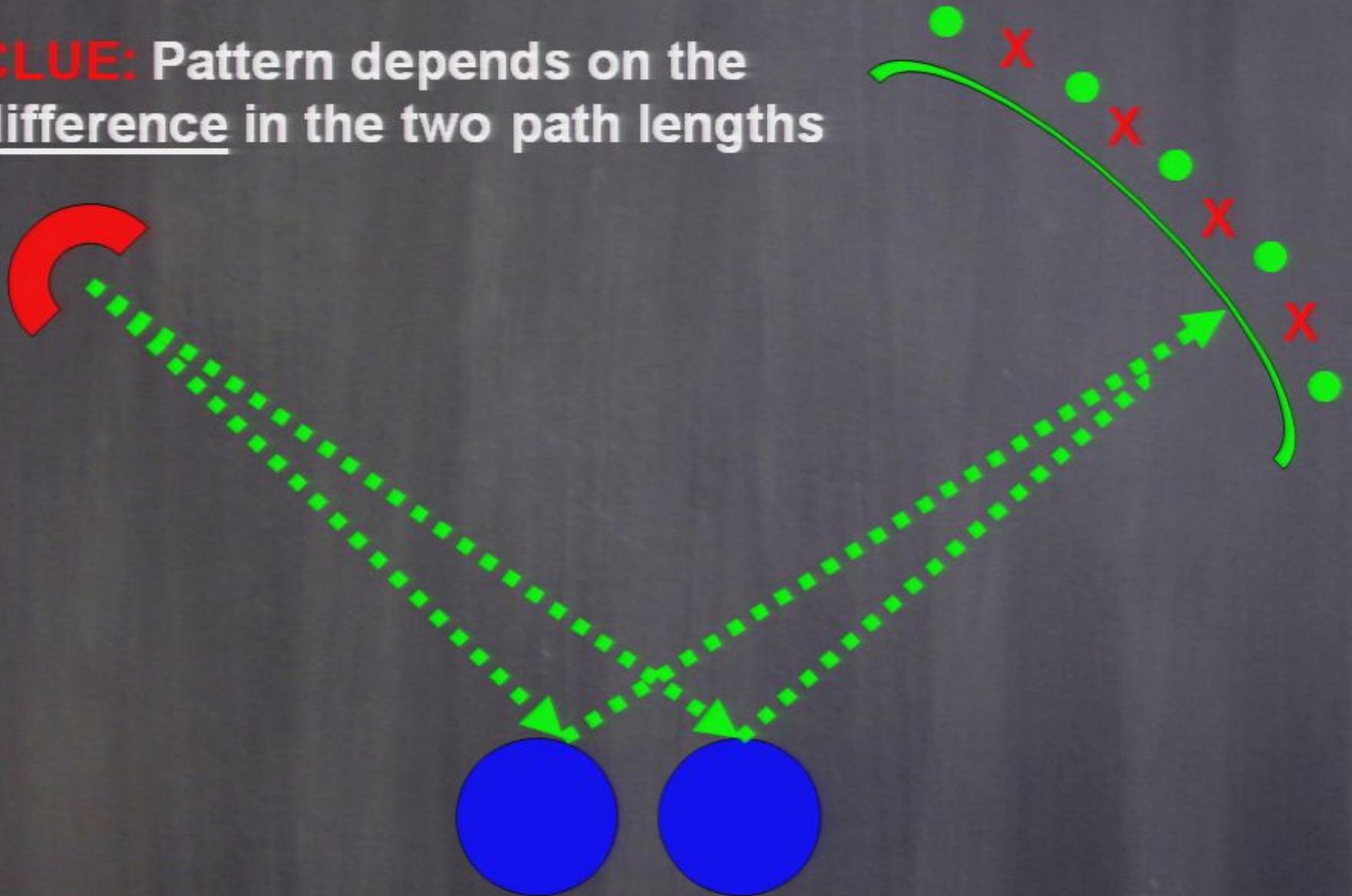
How is this POSSIBLE?

CLUE: Pattern depends on the difference in the two path lengths



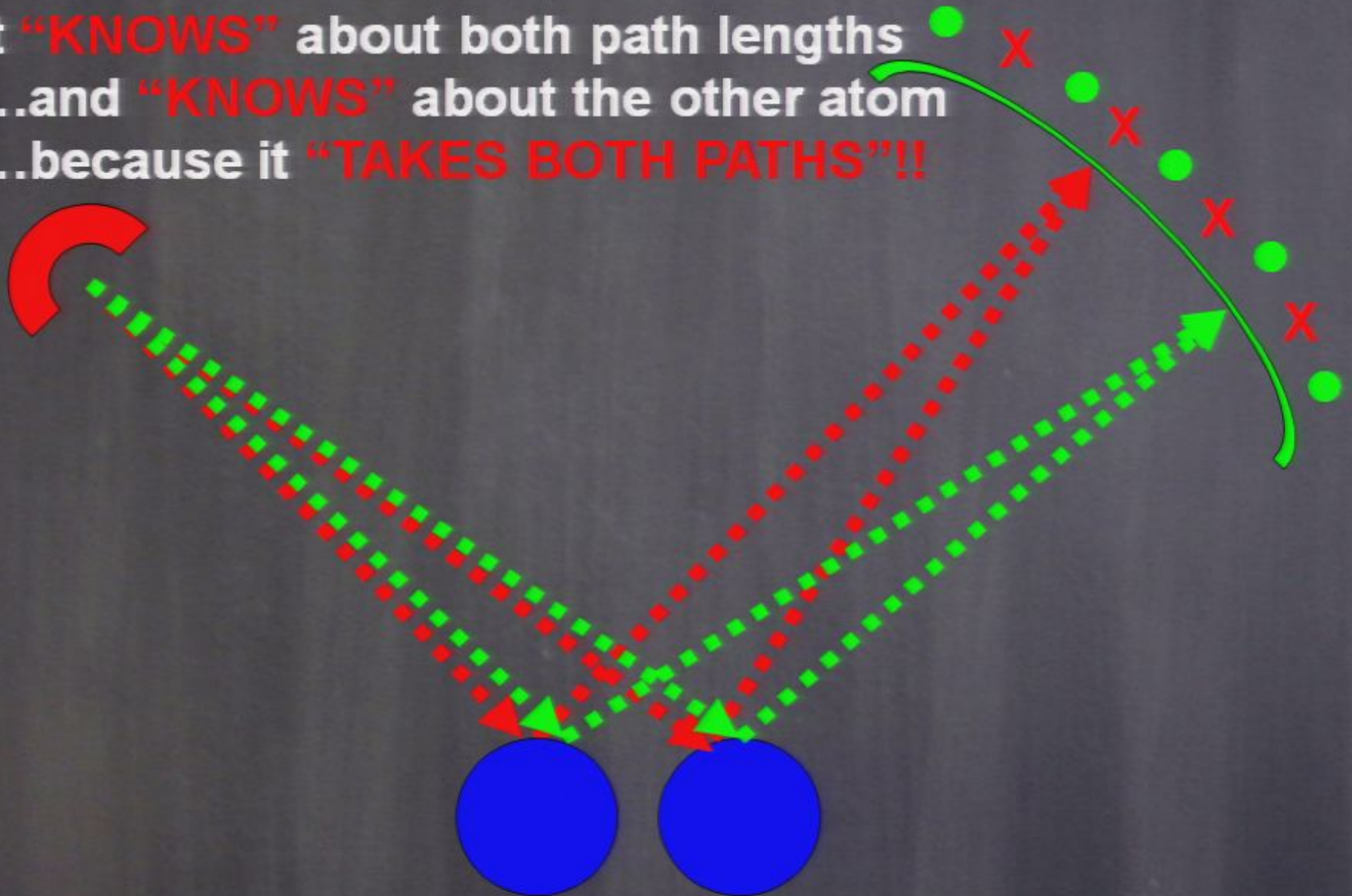
How is this POSSIBLE?

CLUE: Pattern depends on the difference in the two path lengths



How is this **POSSIBLE?**

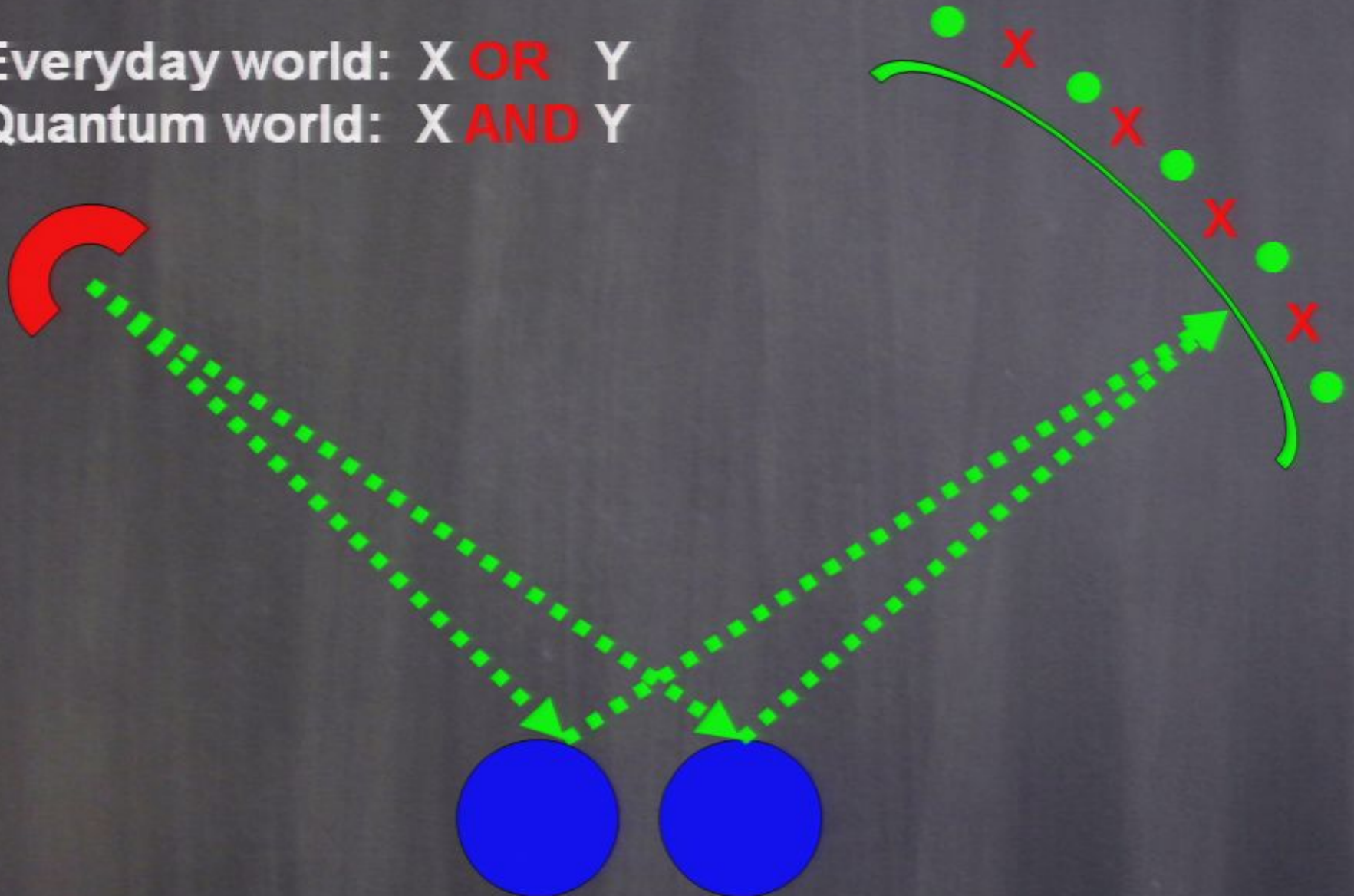
It **“KNOWS”** about both path lengths
...and **“KNOWS”** about the other atom
...because it **“TAKES BOTH PATHS”!!**



How is this POSSIBLE?

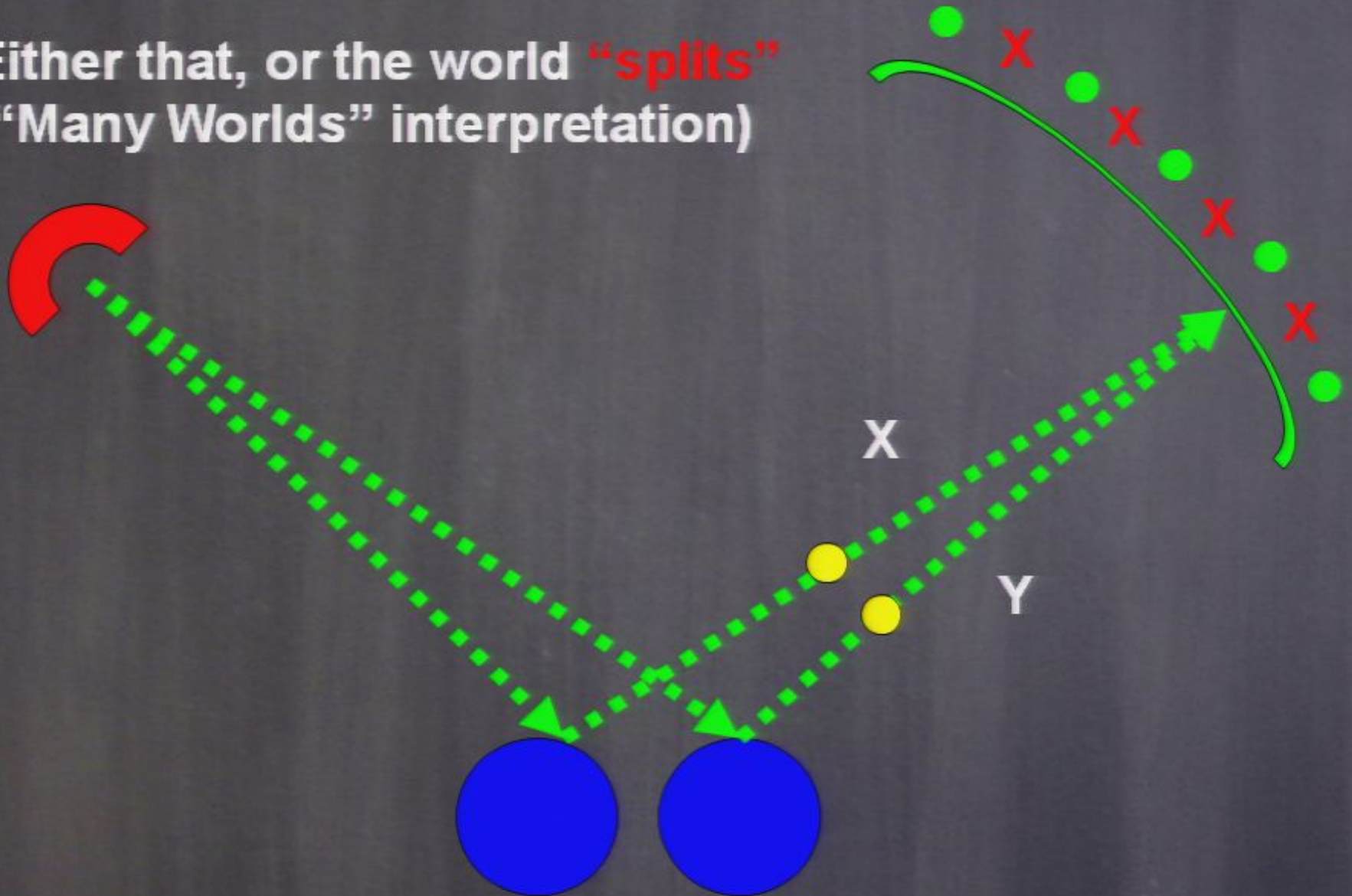
Everyday world: X **OR** Y

Quantum world: X **AND** Y



How is this POSSIBLE?

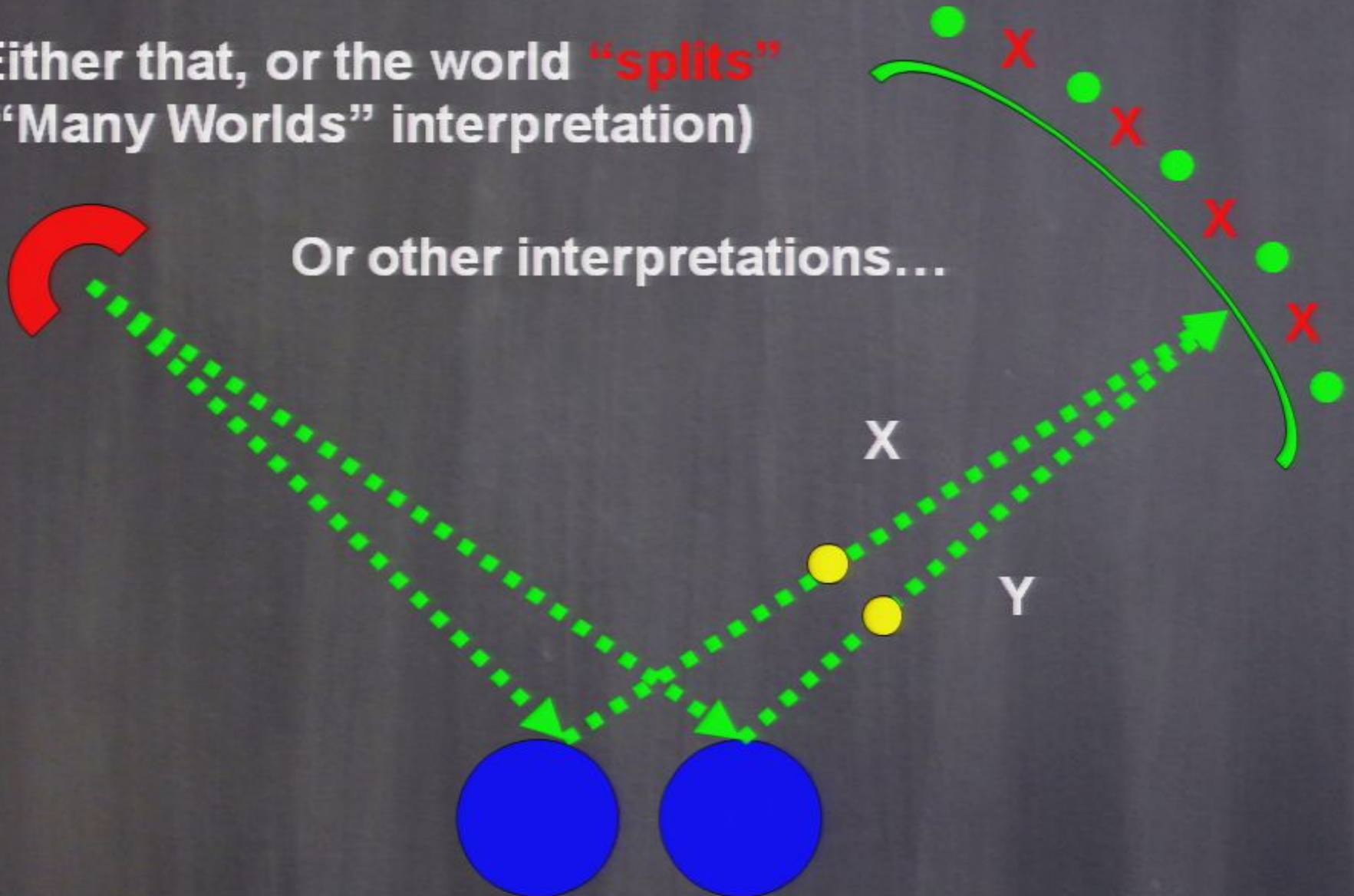
Either that, or the world “splits”
 (“Many Worlds” interpretation)



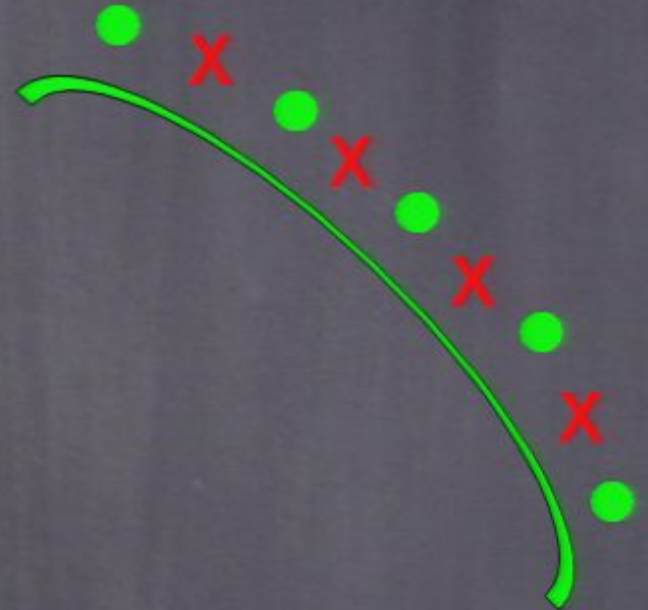
How is this **POSSIBLE?**

Either that, or the world **"splits"**
(**"Many Worlds"** interpretation)

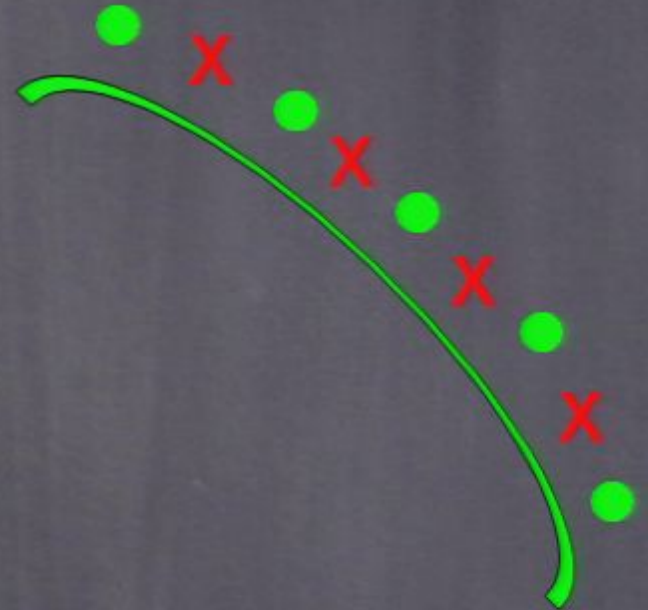
Or other interpretations...



Consider **ALL** the Atoms

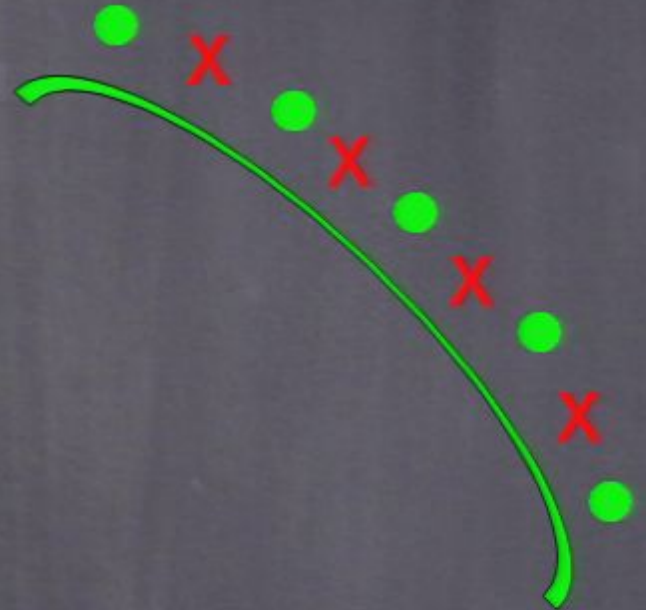


Consider **ALL** the Atoms



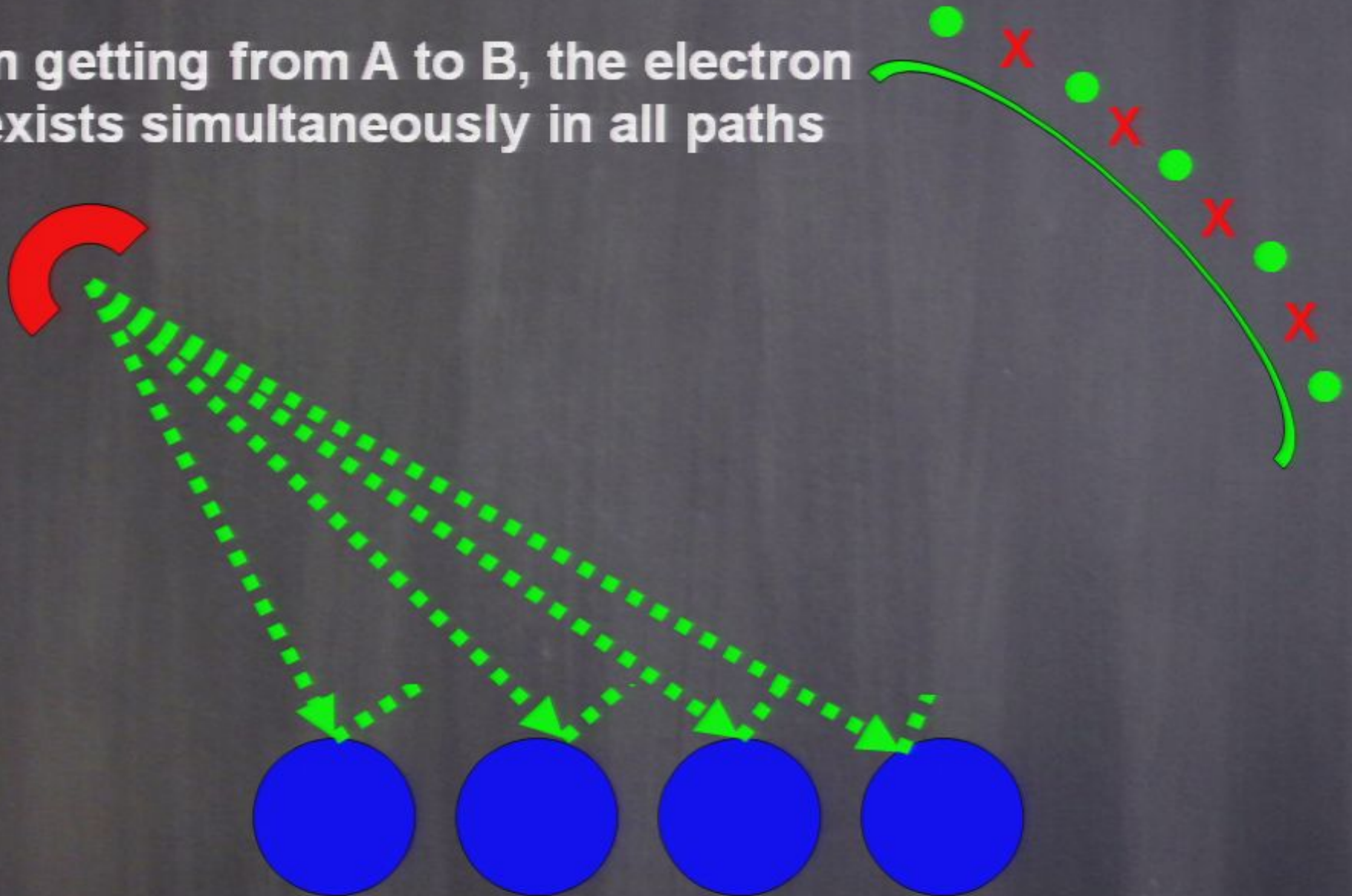
Consider **ALL** the Atoms

In getting from A to B, the electron exists simultaneously in all paths



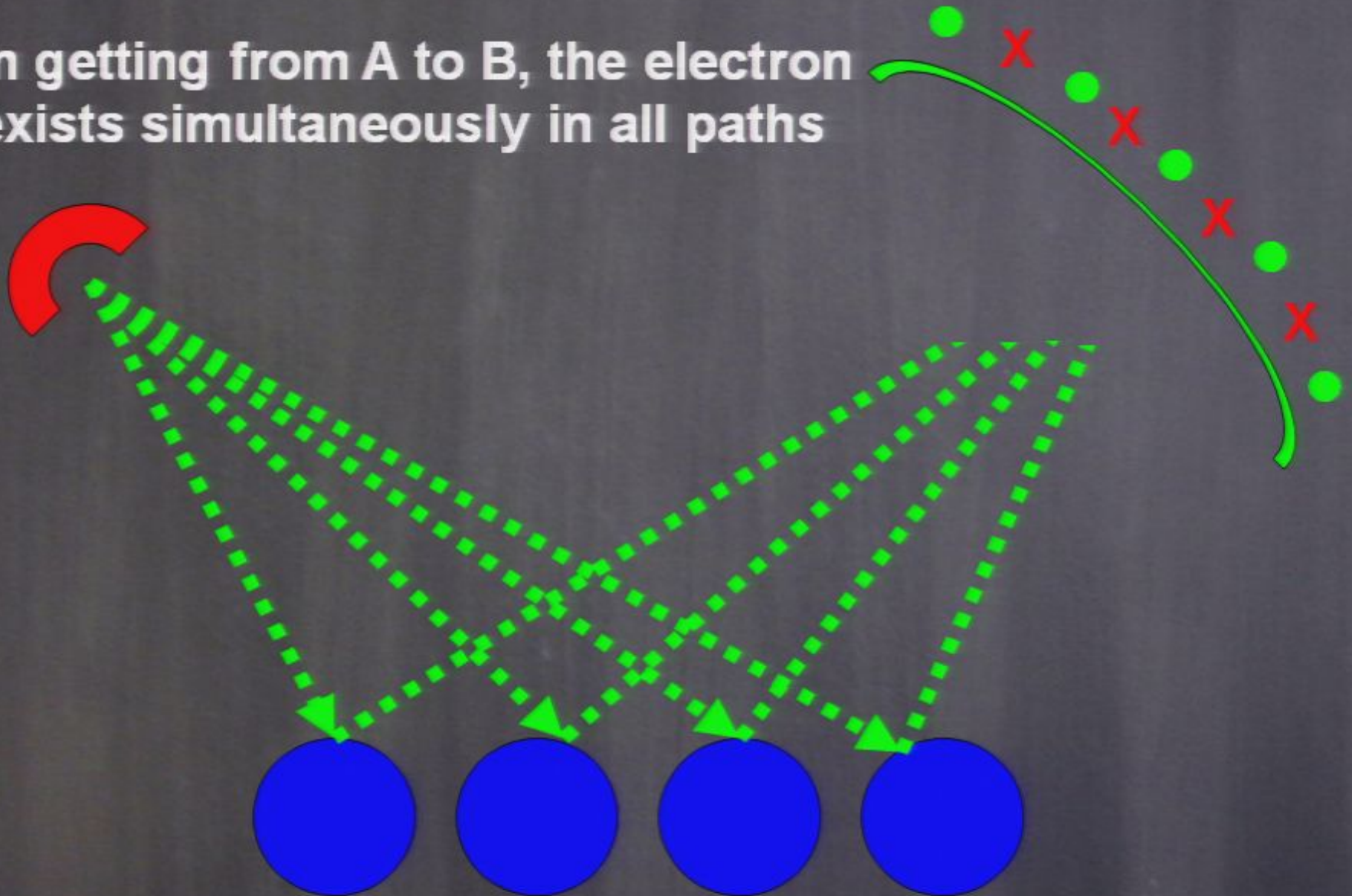
Consider **ALL** the Atoms

In getting from A to B, the electron exists simultaneously in all paths



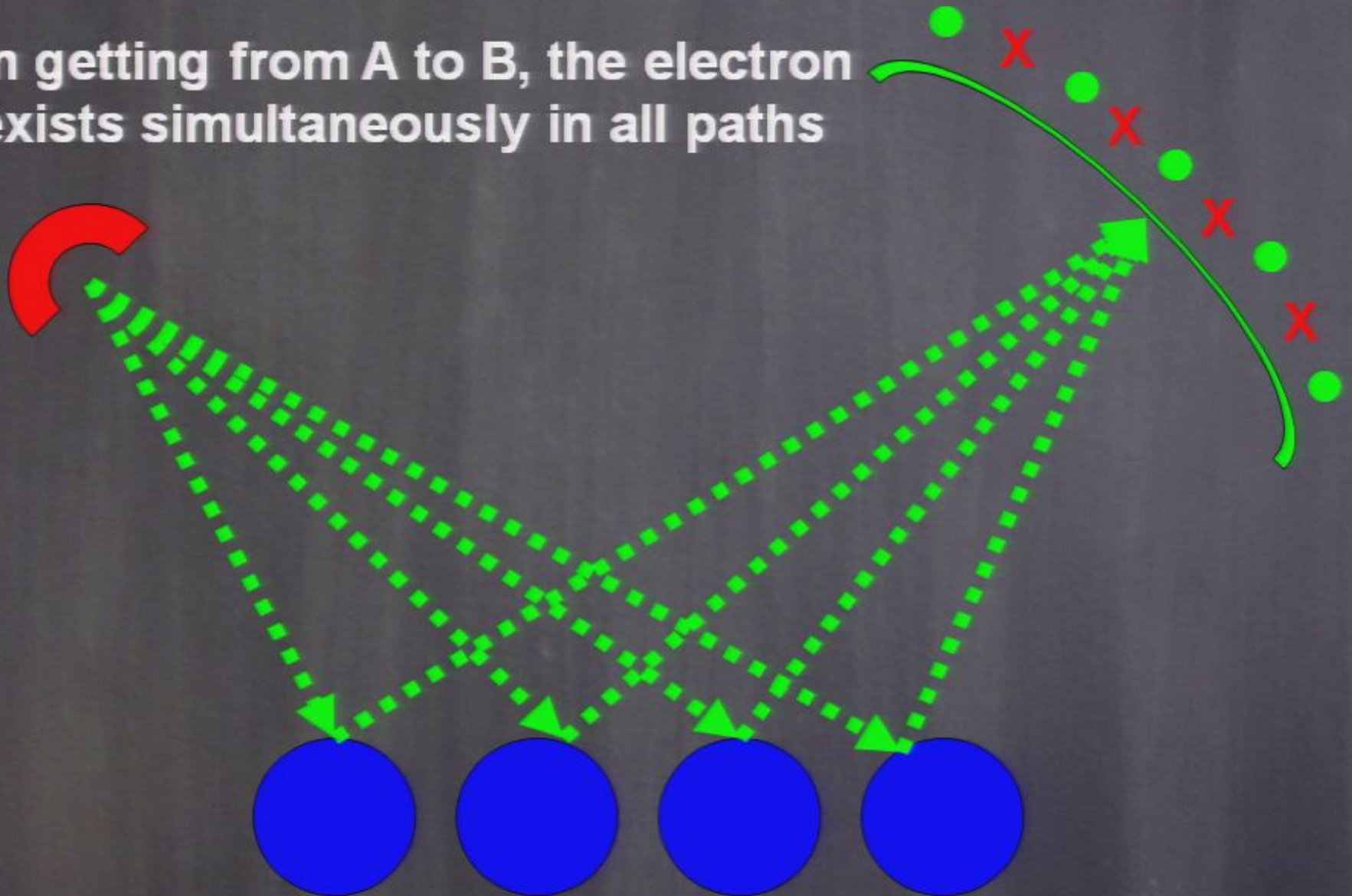
Consider **ALL** the Atoms

In getting from A to B, the electron exists simultaneously in all paths

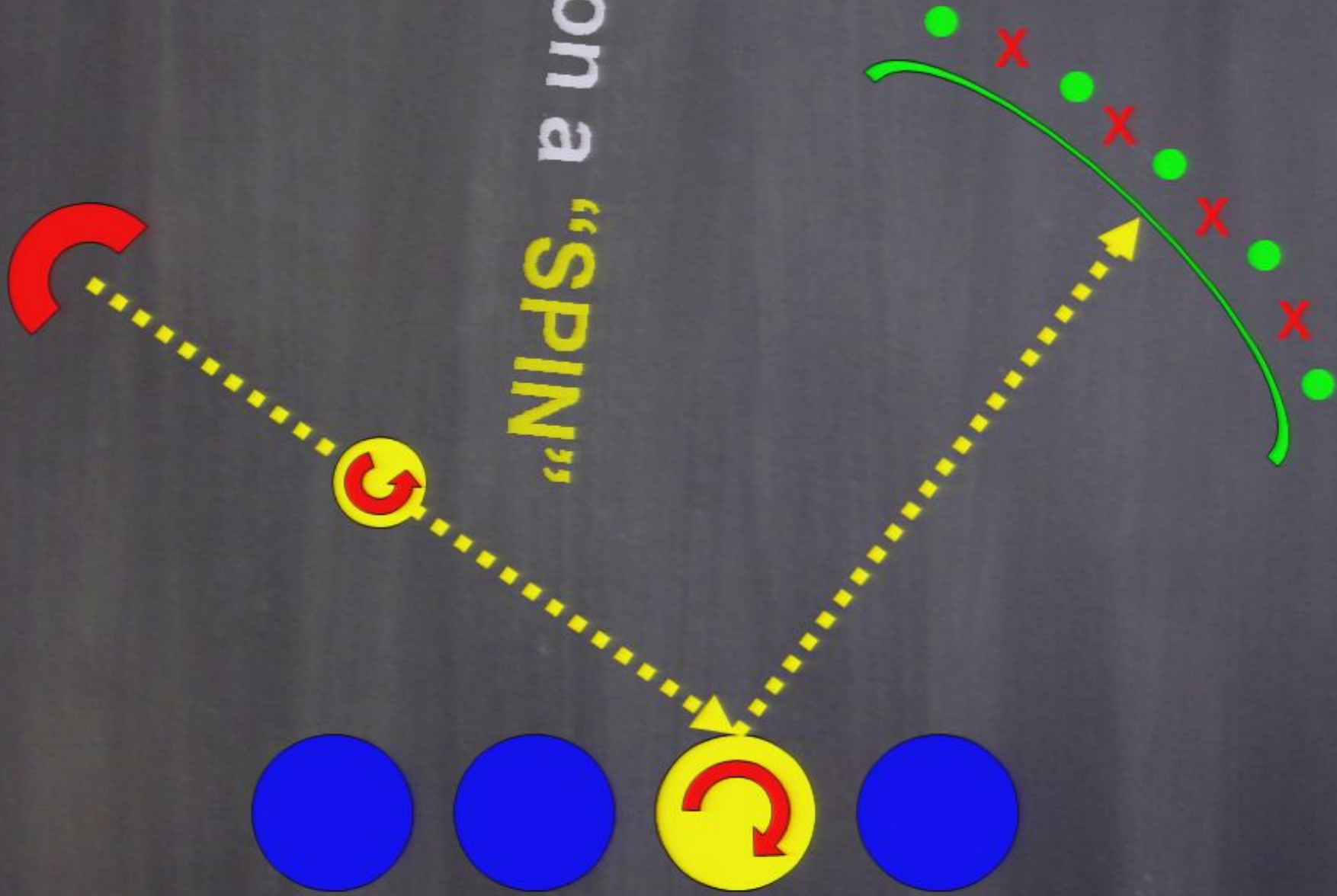


Consider **ALL** the Atoms

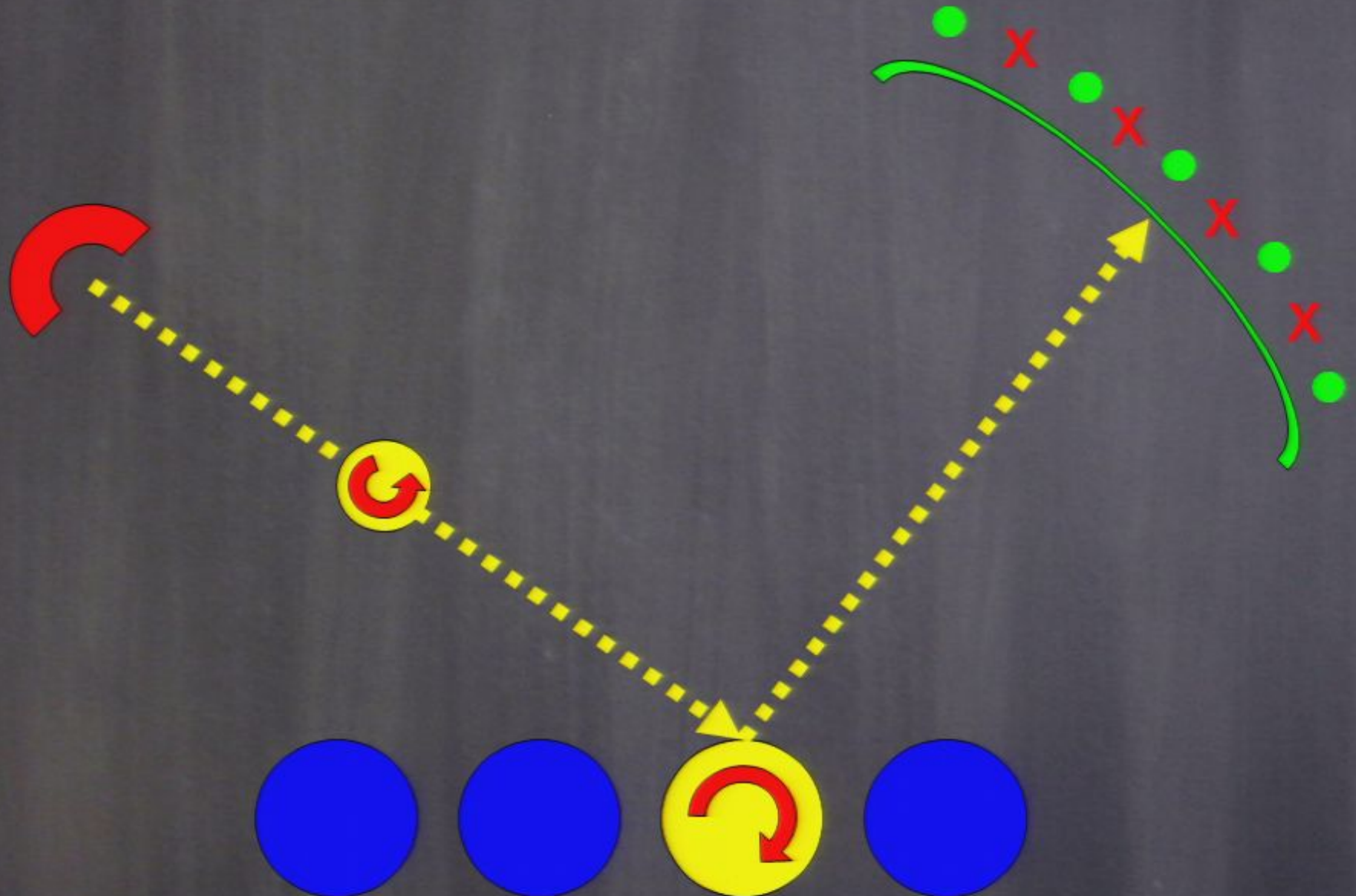
In getting from A to B, the electron exists simultaneously in all paths



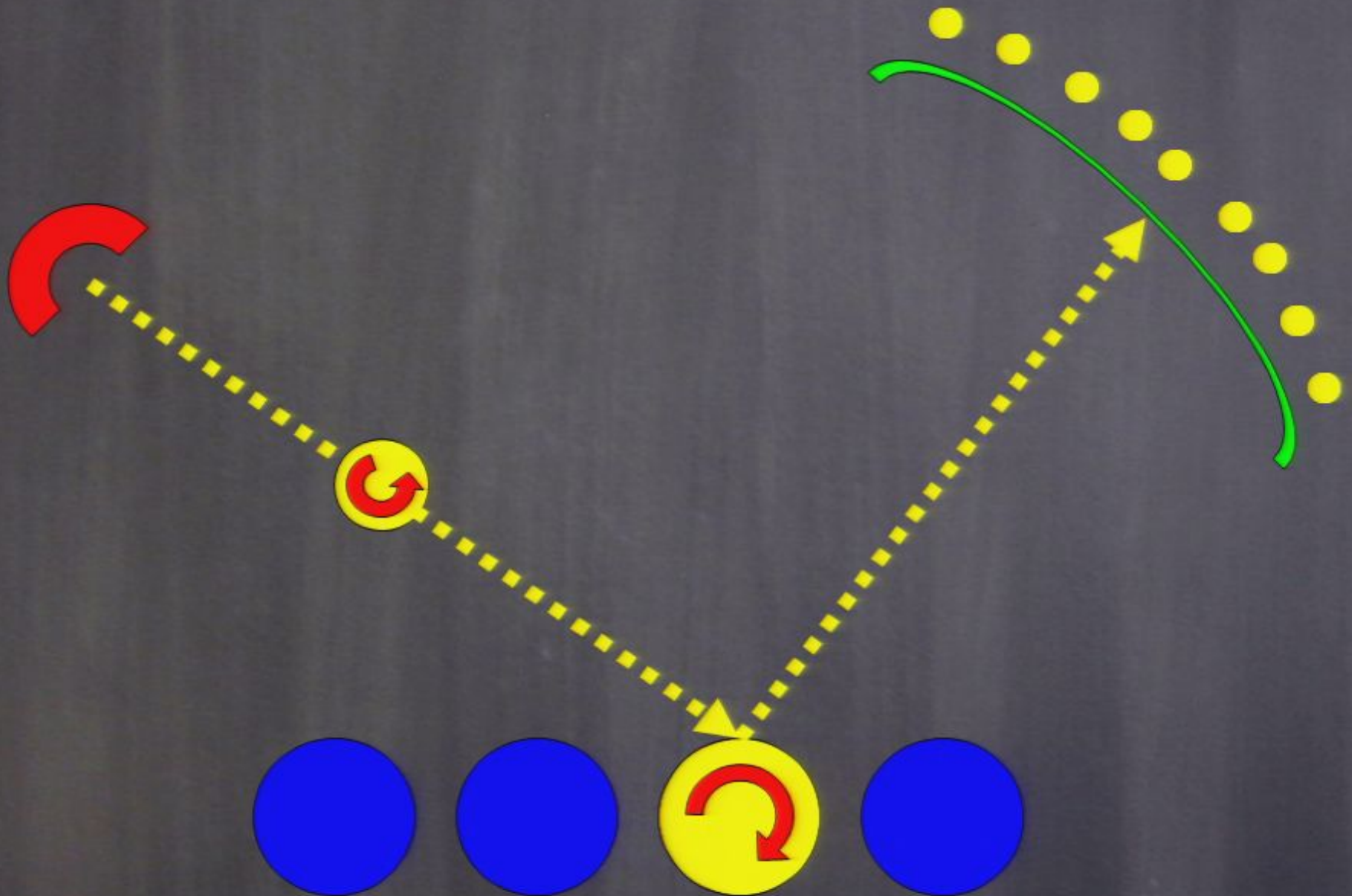
Electron a "SPIN"



Give the Electron a "SPIN"



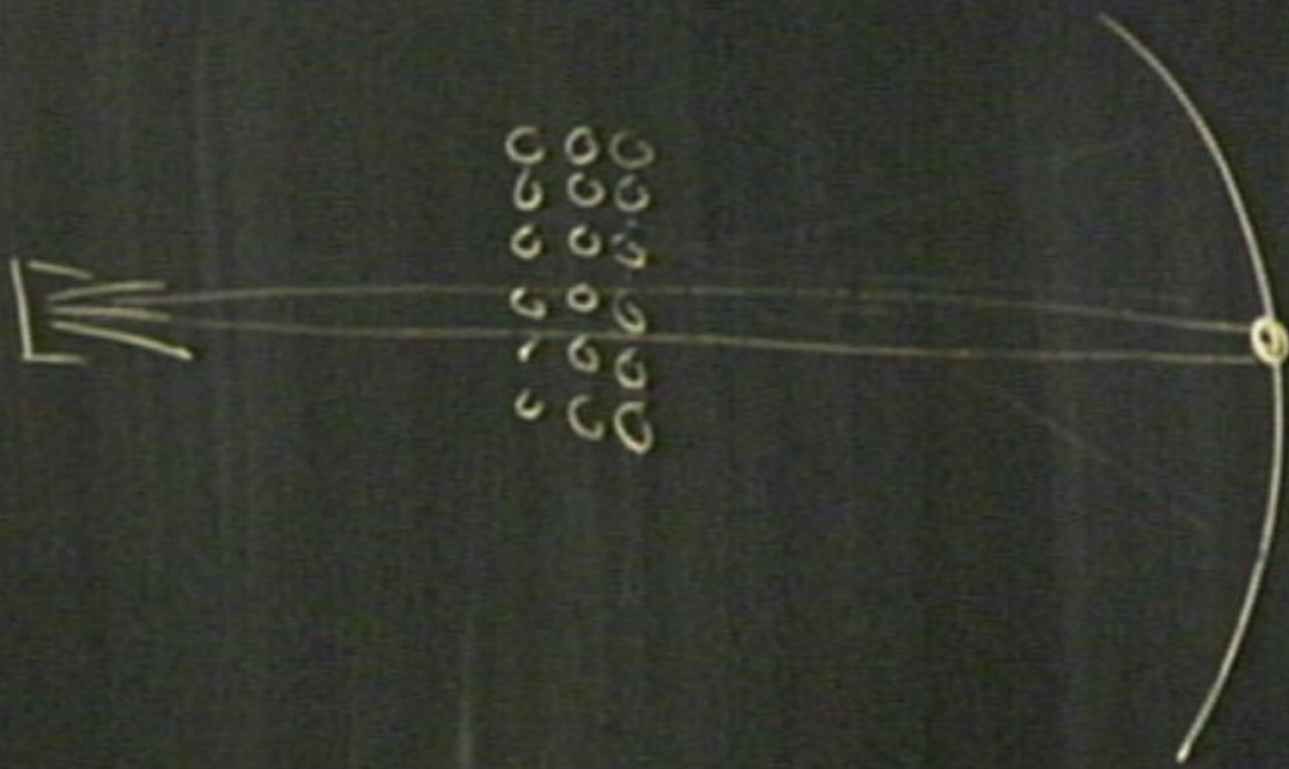
Give the Electron a "SPIN"

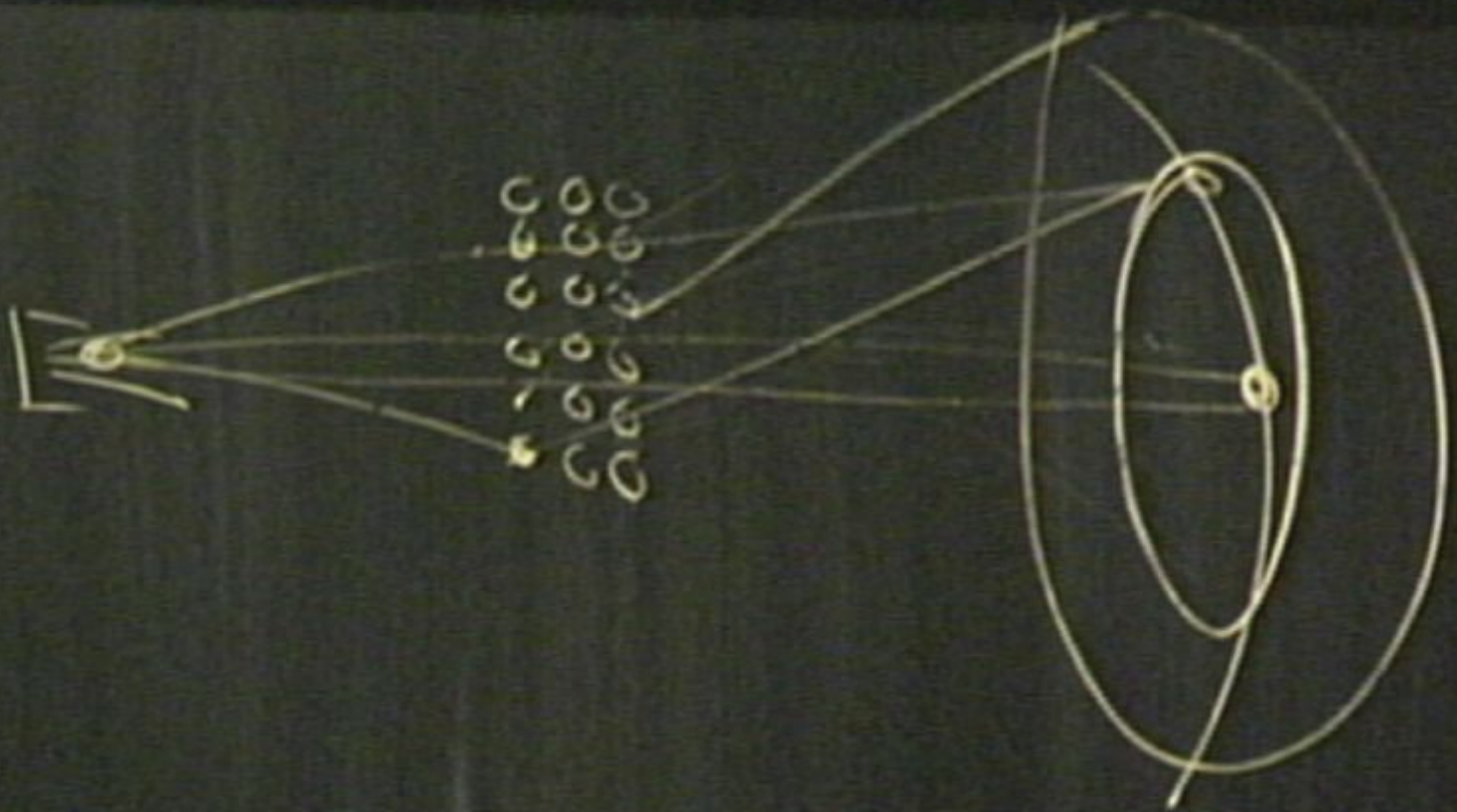




0 0 0
0 0 0
0 0 0
0 0 0
0 0 0
0 0 0







Quantum Entanglement 101

Quantum Entanglement 101













Alice



Alice



Bob



Alice



Bob



Alice



Bob



Alice



Bob



Alice



Bob



Alice



Bob



H ————— T



Alice



Bob





Alice

H ————— T

OR

T ————— H



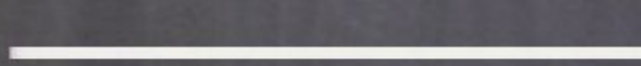
Bob





Alice

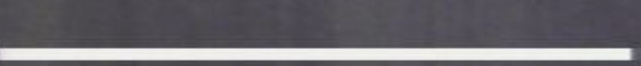
H



T

AND

T



H

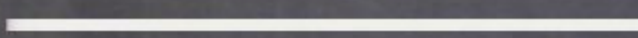


Bob



Alice

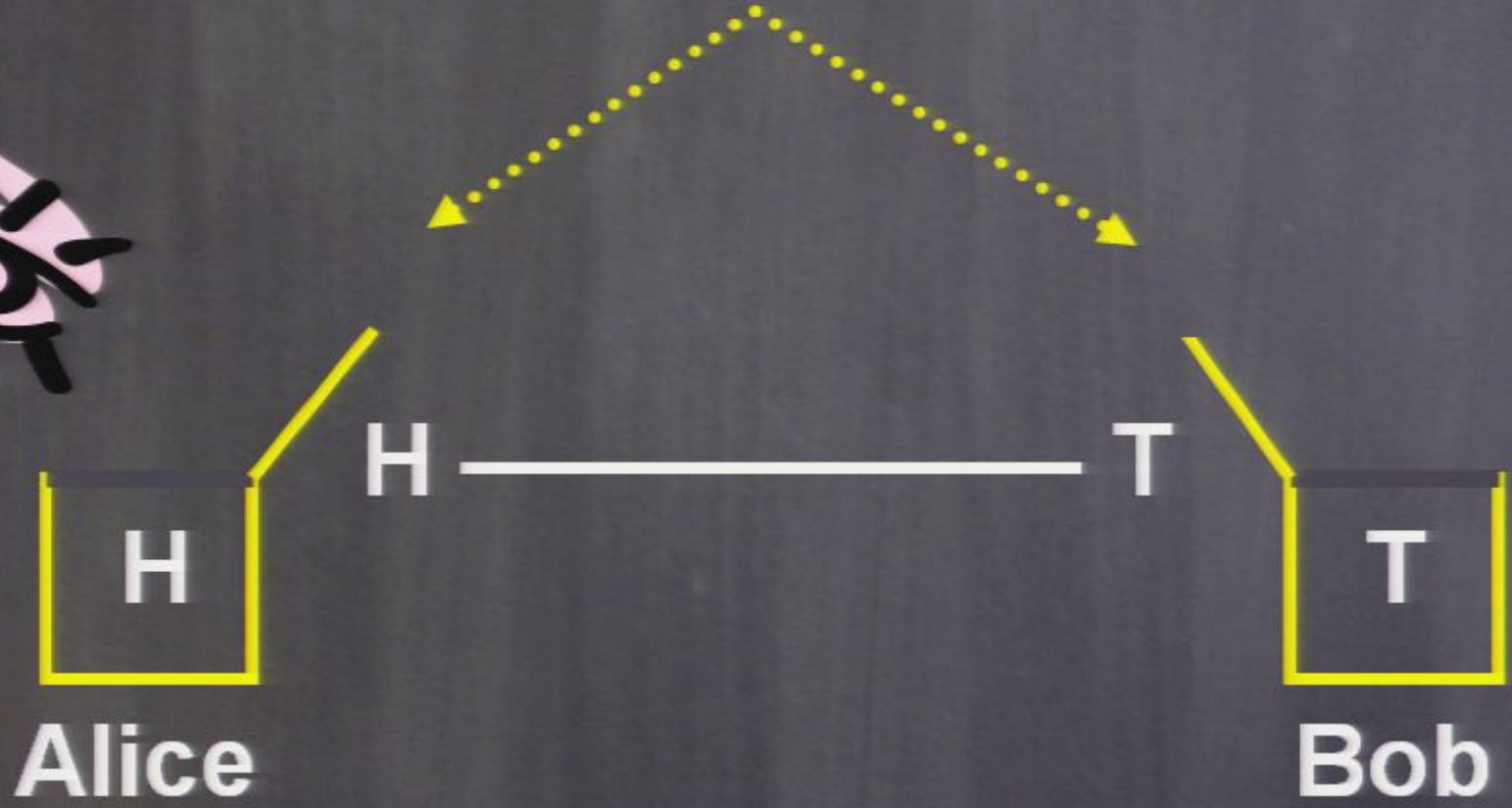
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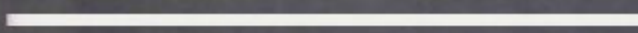
Bob





Alice

H



T



Bob





H ————— T



Alice



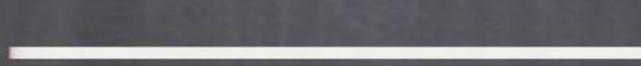
Bob





Alice

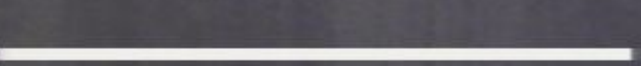
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T

AND

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H



Bob



Alice

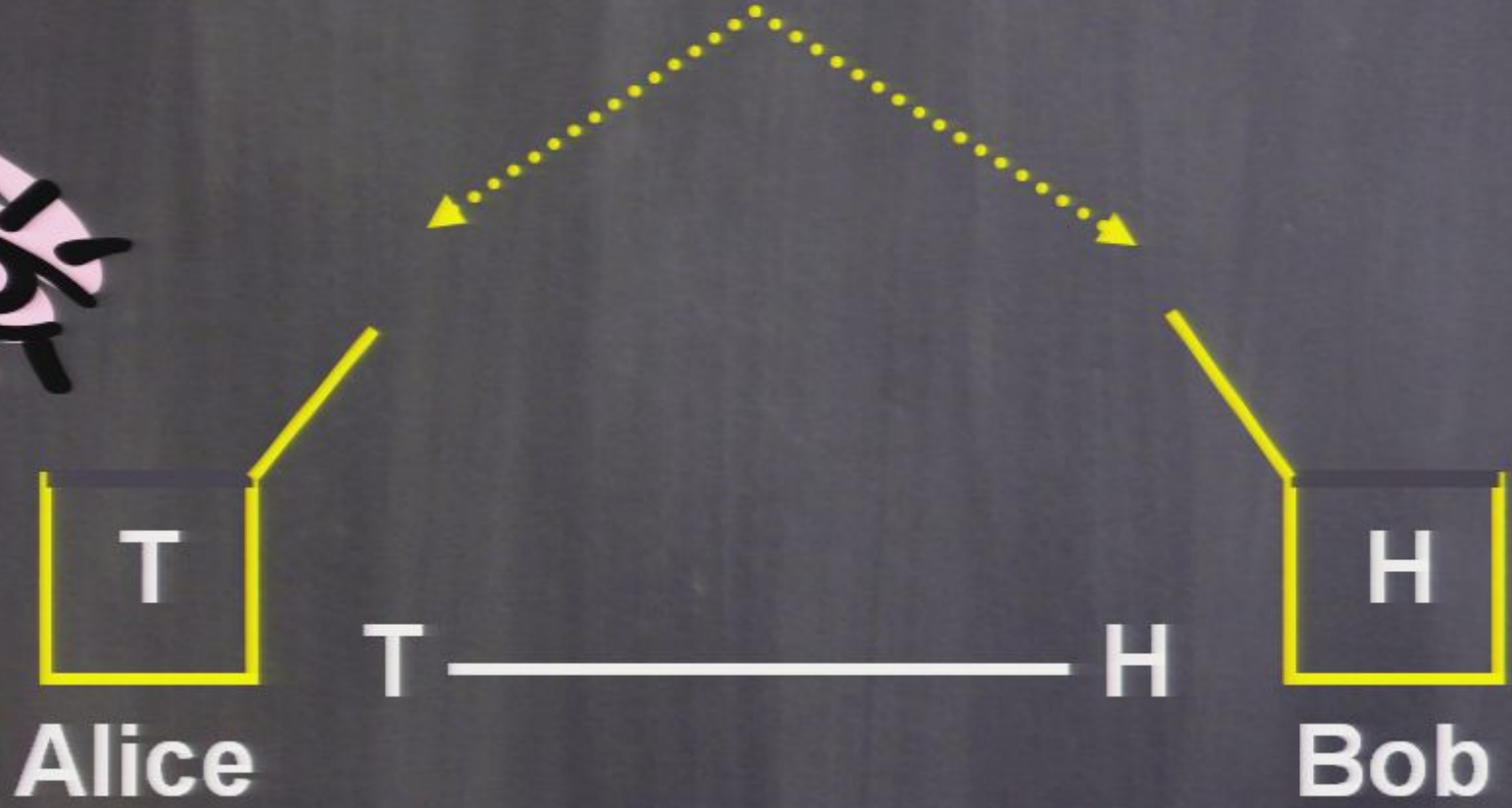
T



H



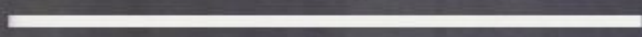
Bob





Alice

T



H



Bob





Alice

T

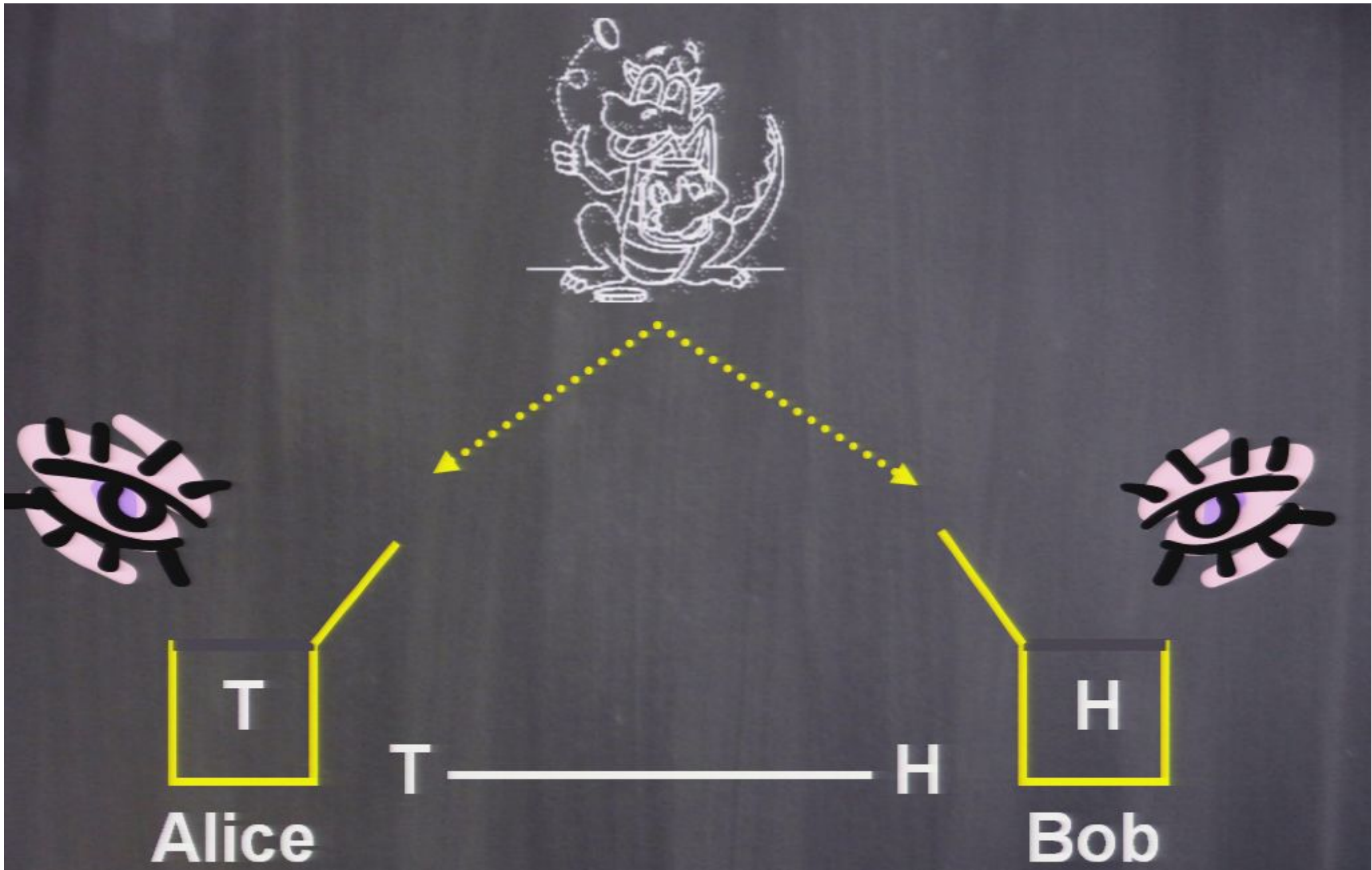


H



Bob





Einstein: "Spooky action at a distance"