

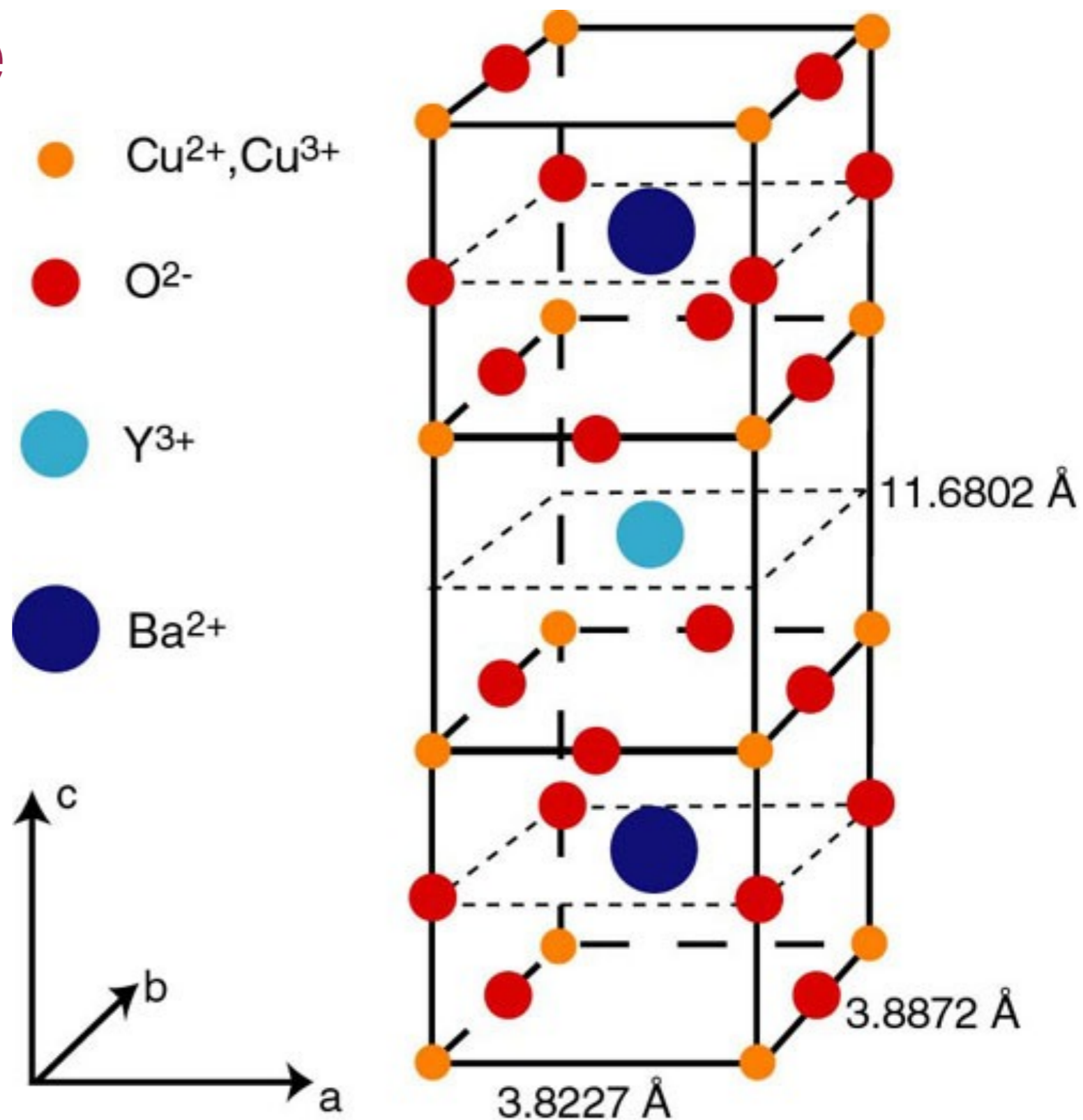
Superconductivity and Quantum Entanglement

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MAGNET is being levitated by an unseen superconductor in which countless trillions of electrons form a vast interconnected quantum state.

High temperature superconductors



Key question:

Can we use the fundamental principles of quantum mechanics to understand why $\text{YBa}_2\text{Cu}_3\text{O}_6$ (and not most other combinations of elements) is a high temperature superconductor ?

Demo of levitating superconductor

Fundamental principles of quantum mechanics

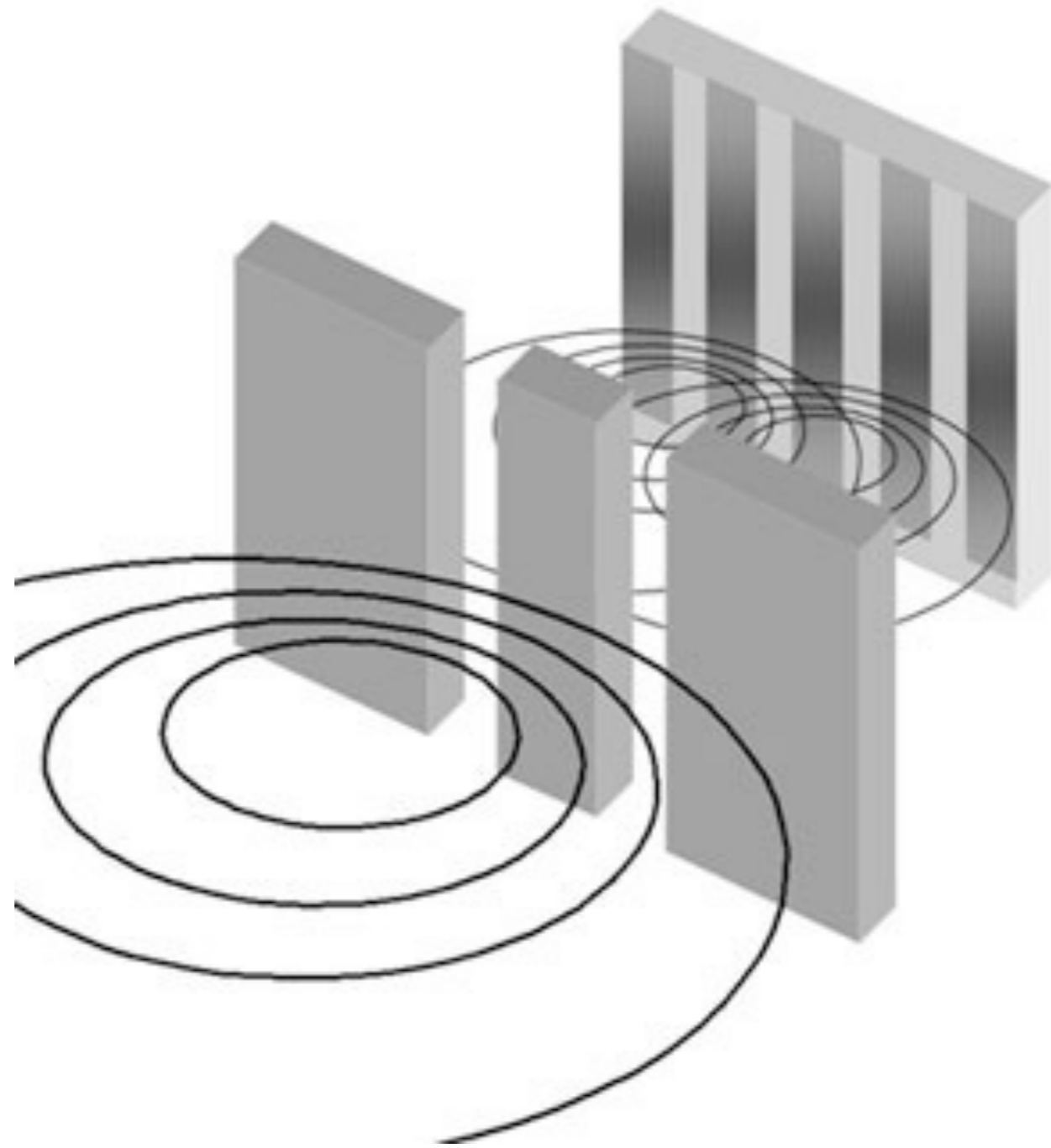
I. A particle is described by its quantum “state”.

Fundamental principles of quantum mechanics

1. A particle is described by its quantum “state”.

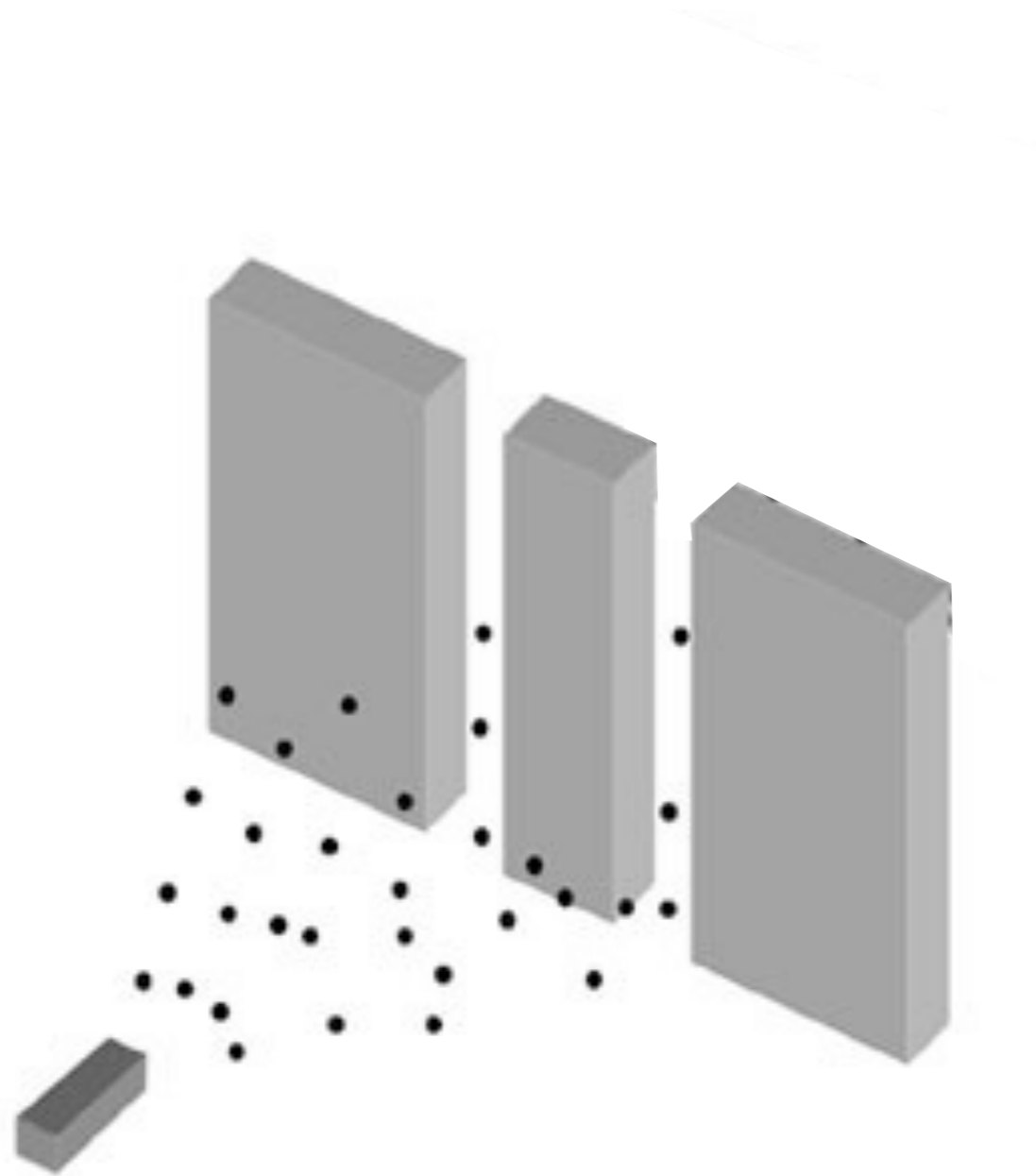
2. Linear superposition: particles can be in the sum or difference of two “states”

The double slit experiment



Interference of water waves

The double slit experiment

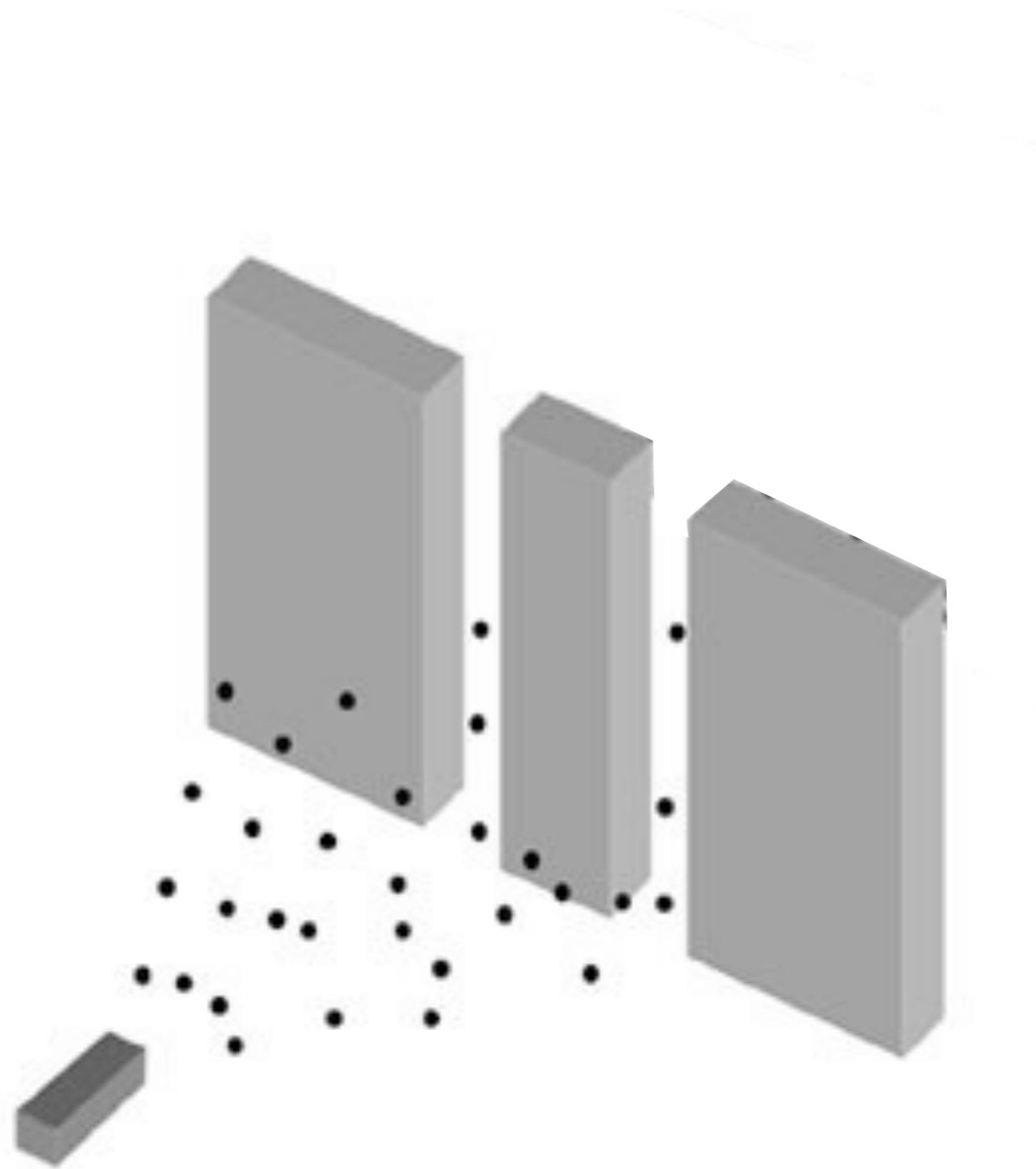


Send electrons through the slits

Show video at <http://www.youtube.com/watch?v=jvO0P5-SMxk>

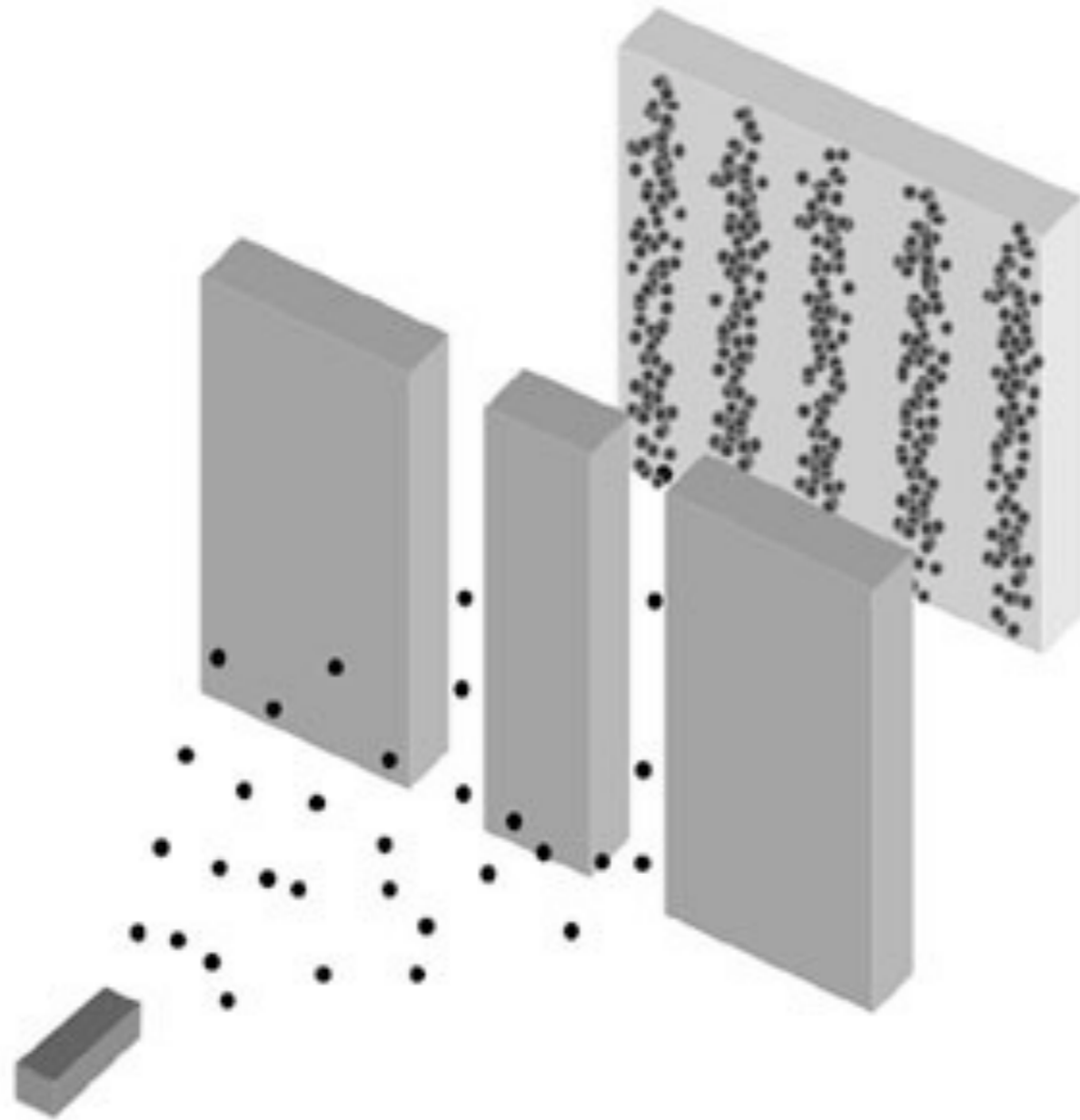


The double slit experiment



Send electrons through the slits

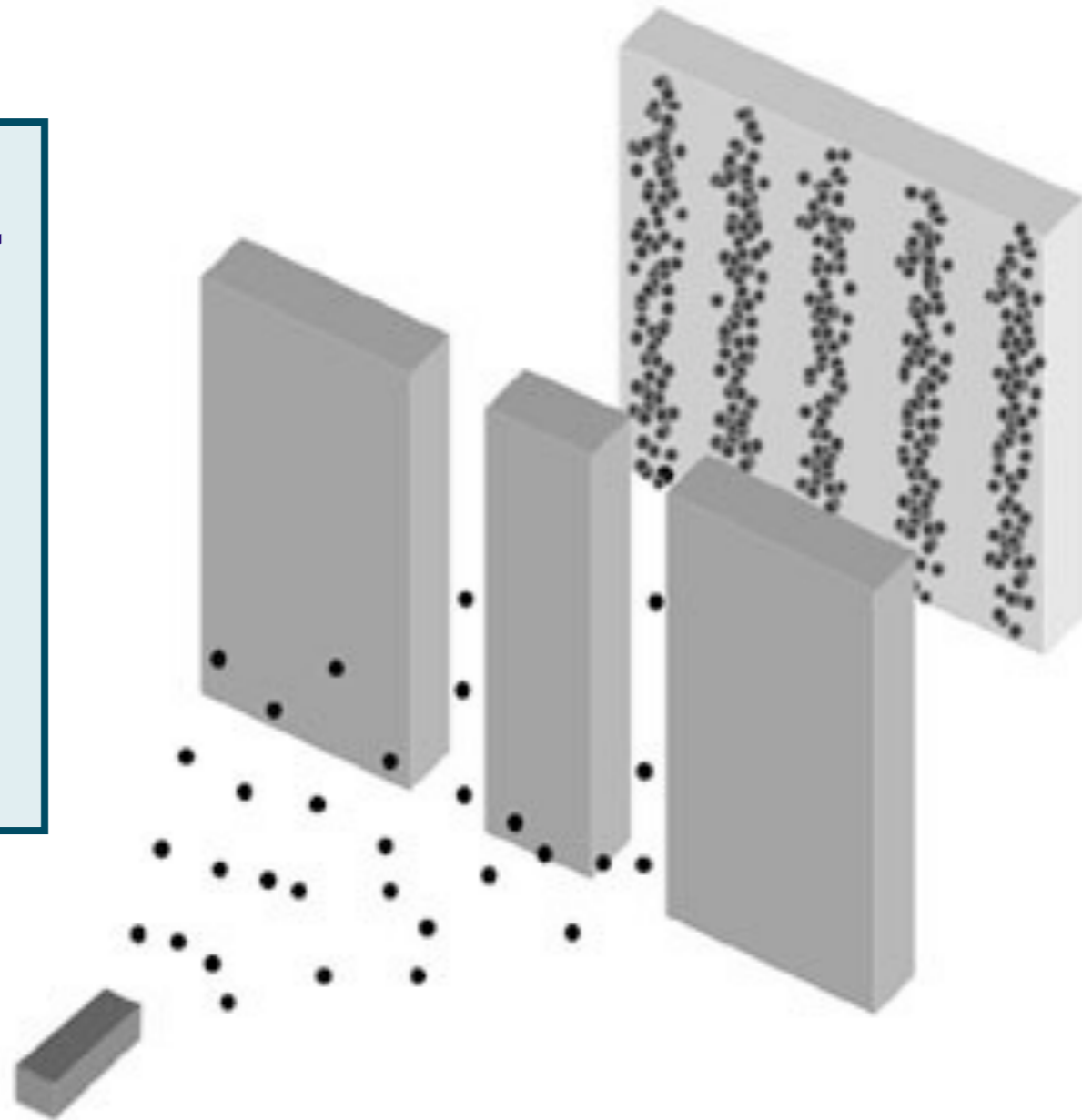
The double slit experiment



Interference of electrons

The double slit experiment

Which slit
does an
electron
pass
through ?

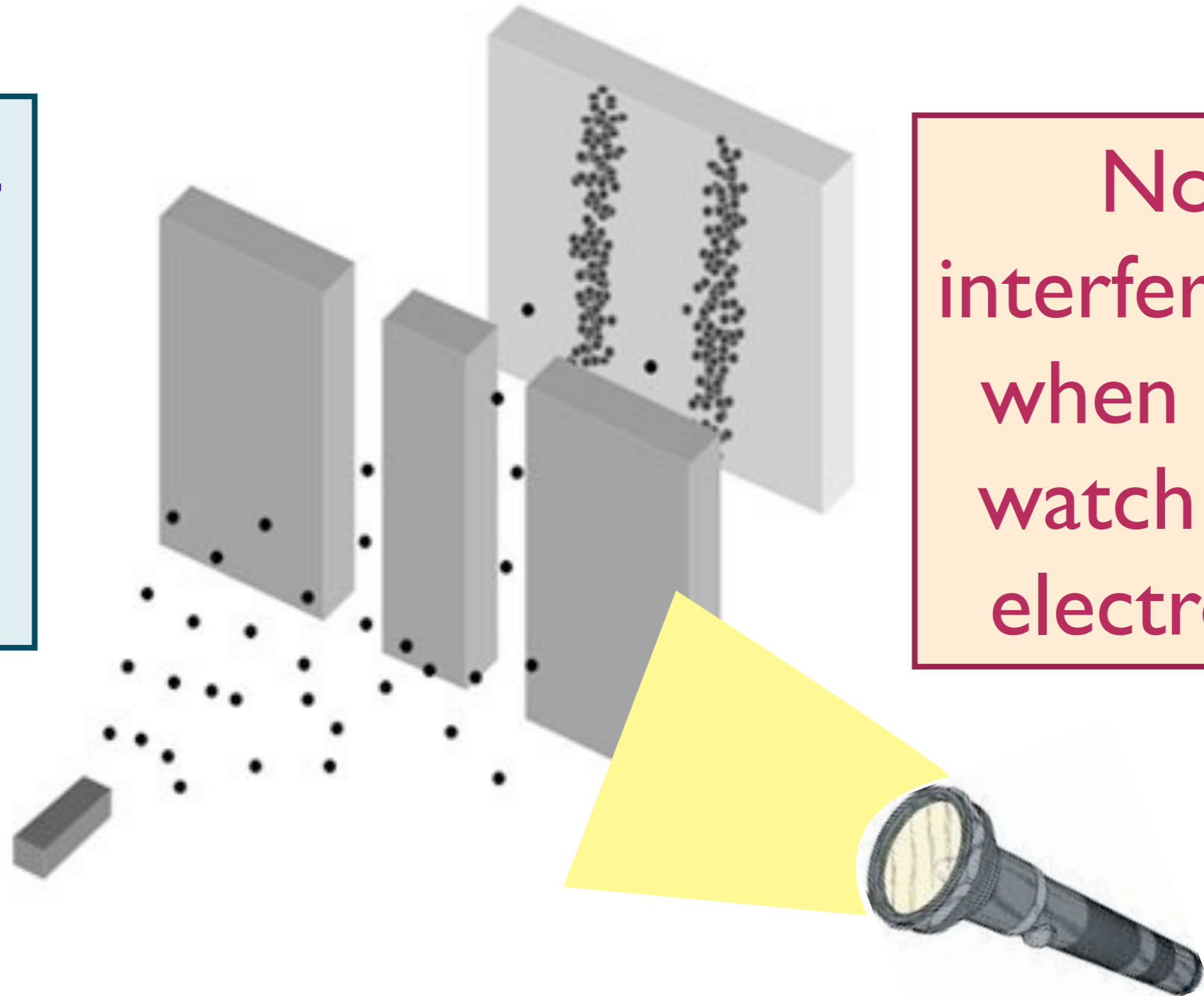


Interference of electrons

Principles of Quantum Mechanics: I. Quantum Superposition

The double slit experiment

Which slit
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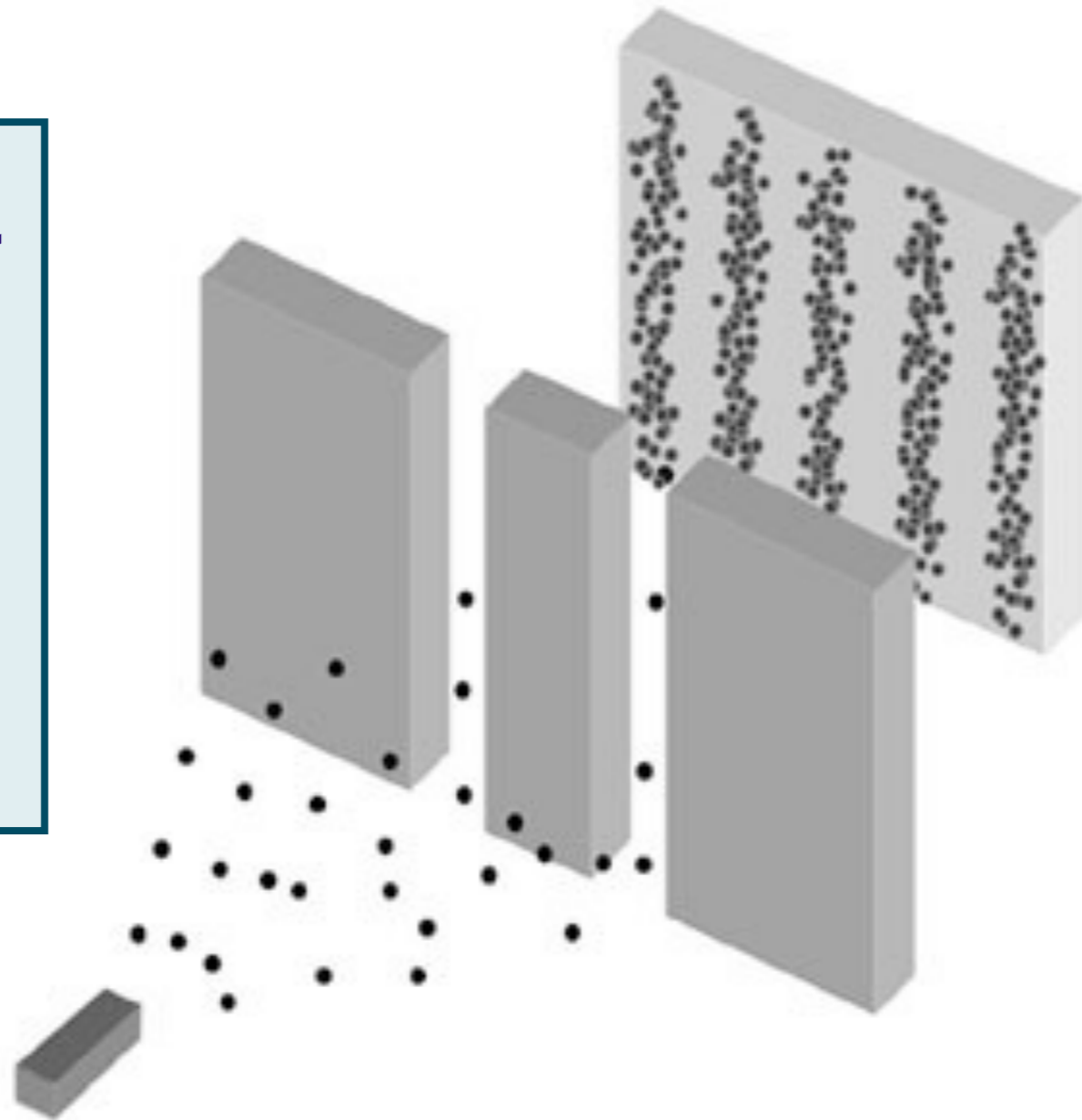
No
interference
when you
watch the
electrons

Interference of electrons

Principles of Quantum Mechanics: I. Quantum Superposition

The double slit experiment

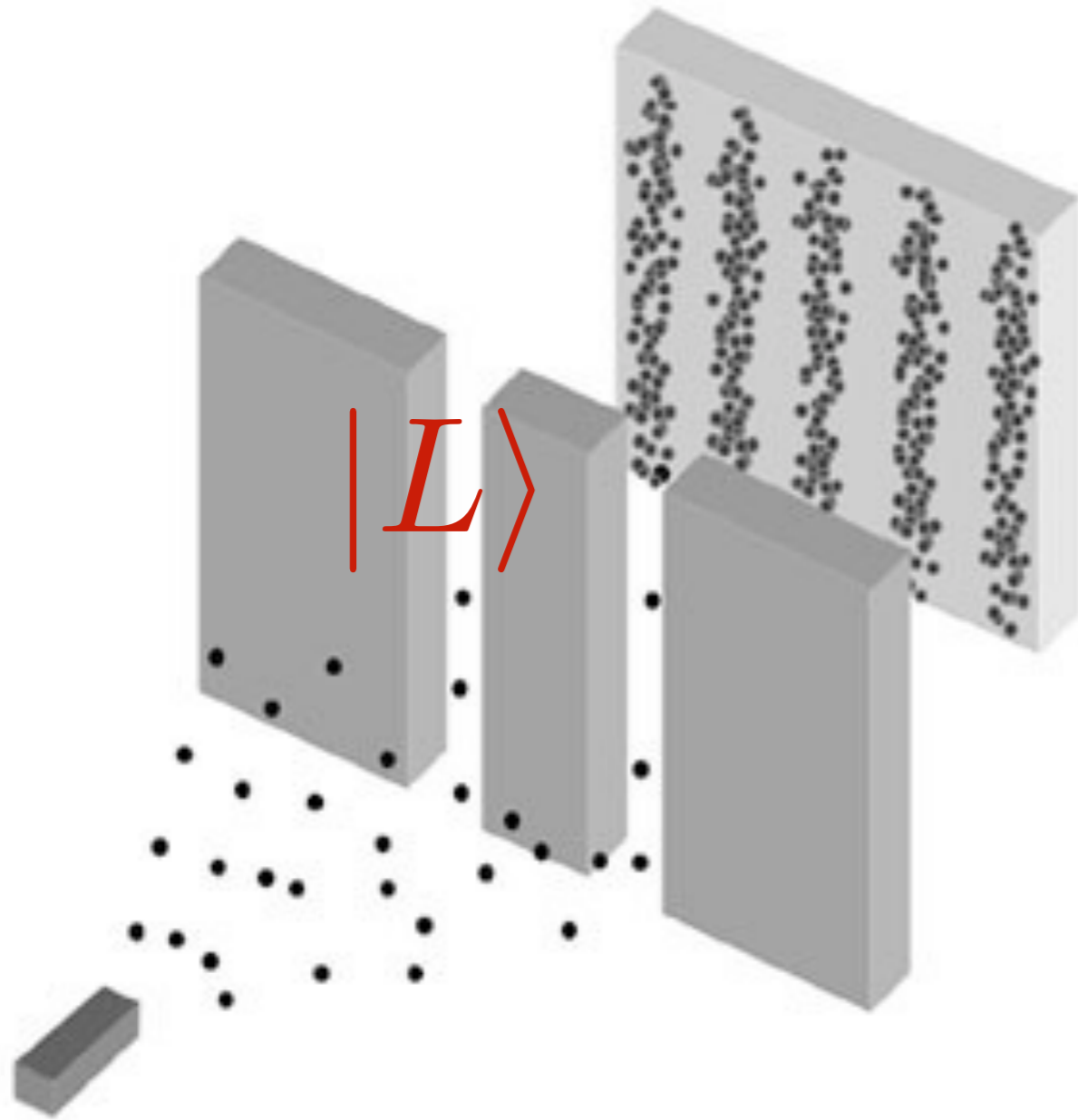
Which slit
does an
electron
pass
through ?



Each
electron
passes
through
both slits !

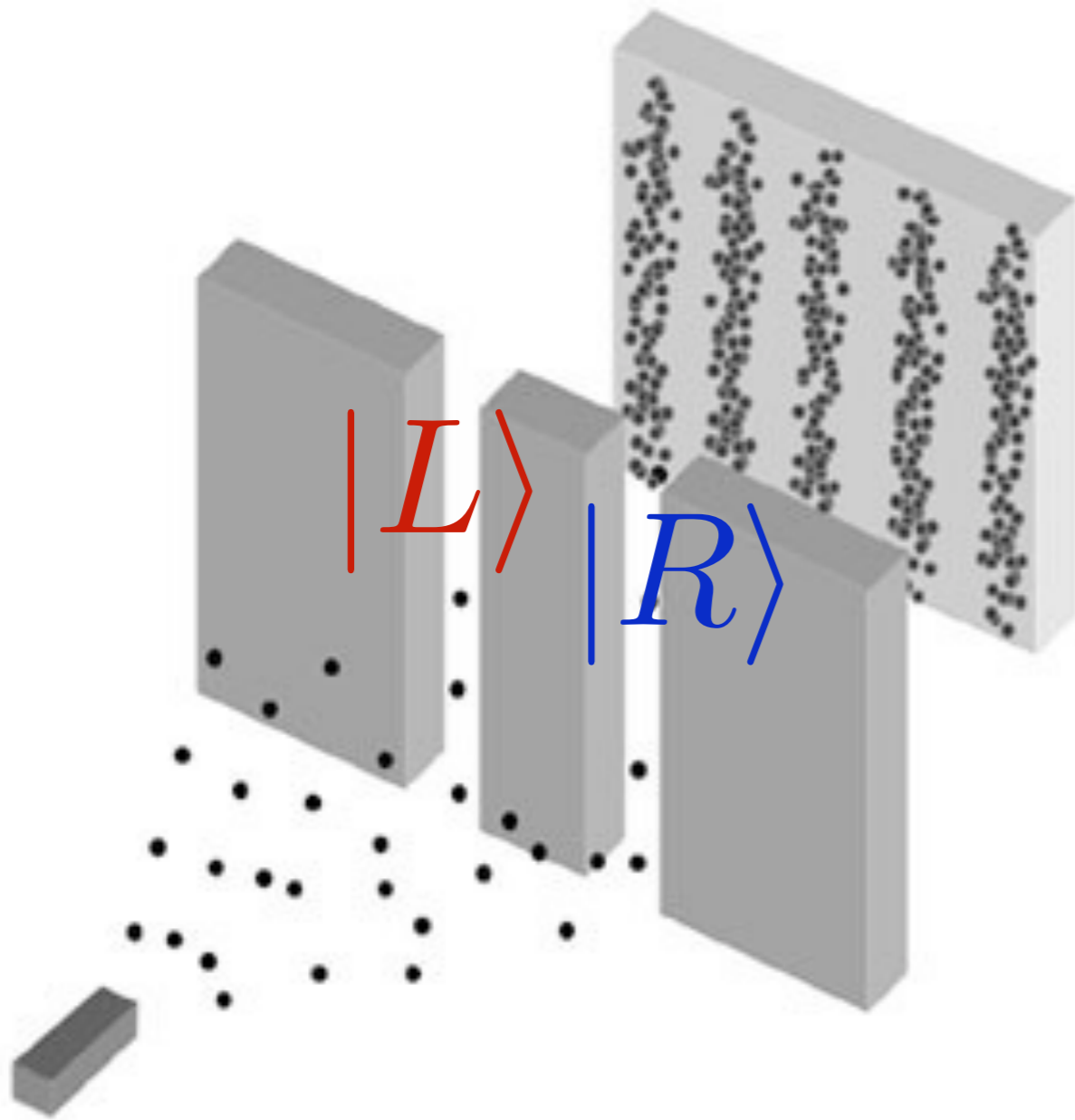
Interference of electrons

The double slit experiment



Let $|L\rangle$ represent the state with the electron in the left slit

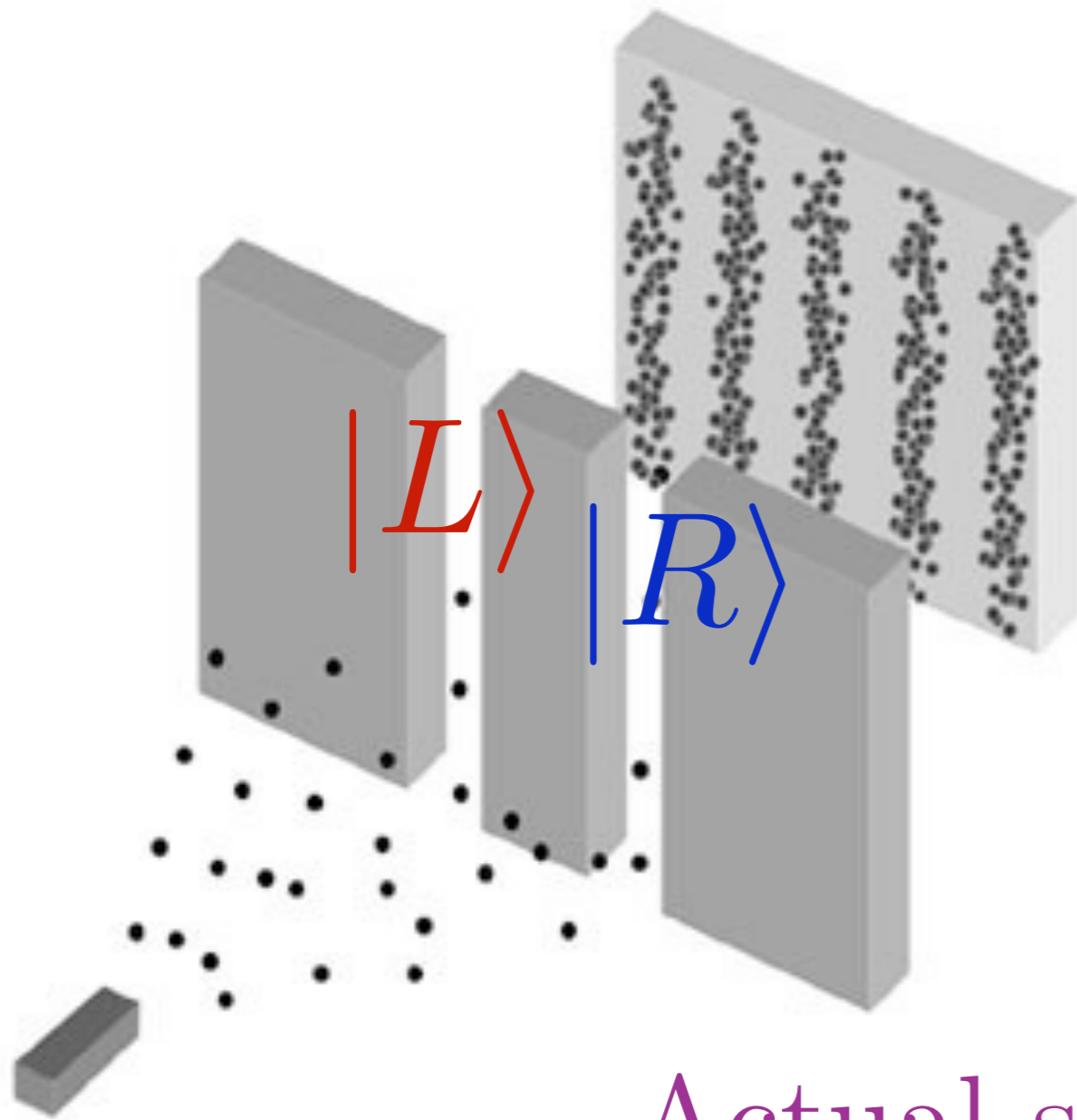
The double slit experiment



Let $|L\rangle$ represent the state with the electron in the left slit

And $|R\rangle$ represents the state with the electron in the right slit

The double slit experiment



Let $|L\rangle$ represent the state with the electron in the left slit

And $|R\rangle$ represents the state with the electron in the right slit

Actual state of the electron is

$$|L\rangle + |R\rangle$$

Fundamental principles of quantum mechanics

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Fundamental principles of quantum mechanics

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2. Linear superposition: particles can be in the sum or difference of two “states”
3. Entanglement: state superposition with many particles.

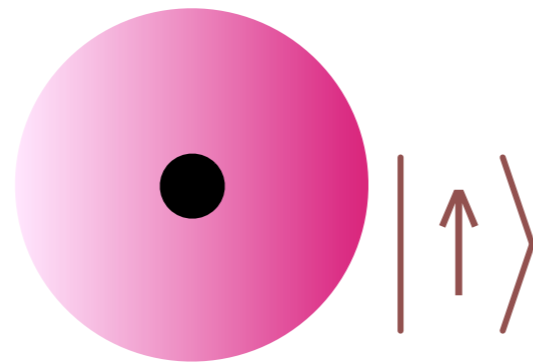
Principles of Quantum Mechanics: II. Quantum Entanglement

Quantum Entanglement: quantum superposition
with more than one particle

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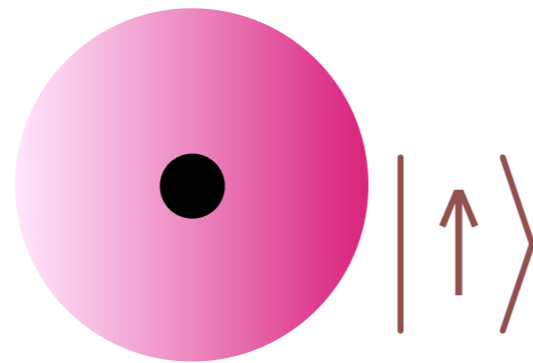
Hydrogen atom:



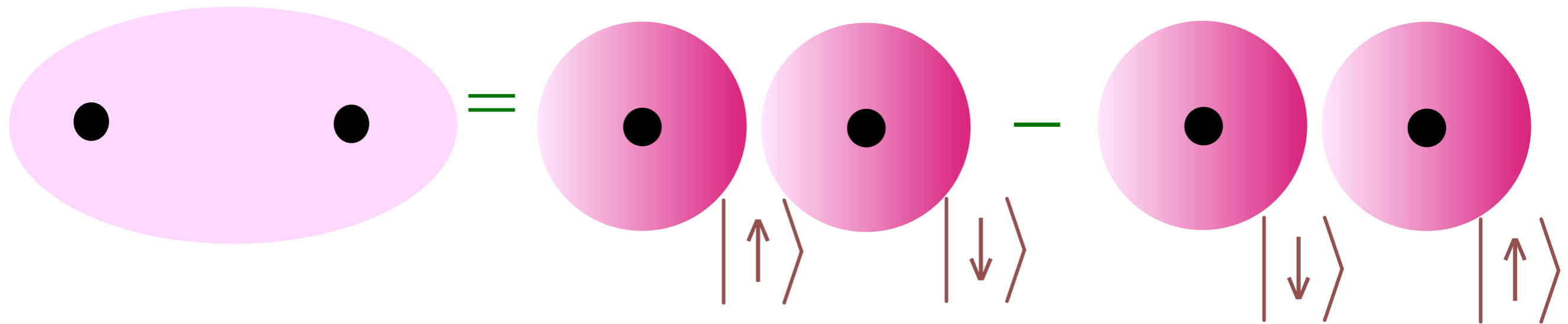
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Hydrogen atom:



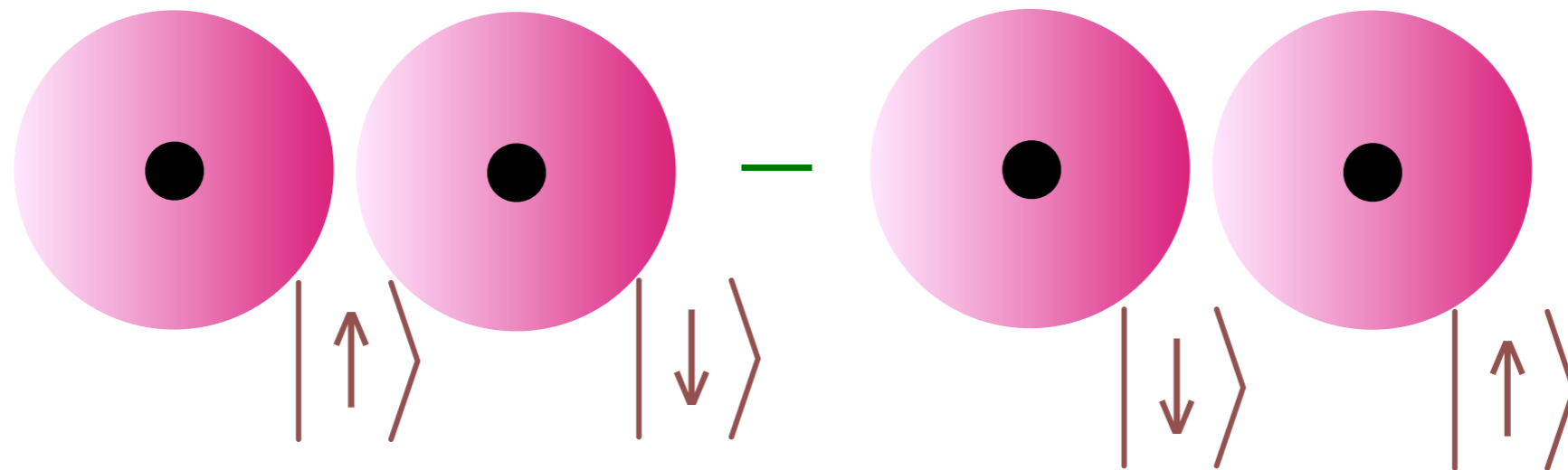
Hydrogen molecule:



$$= \frac{1}{\sqrt{2}} (|\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle)$$

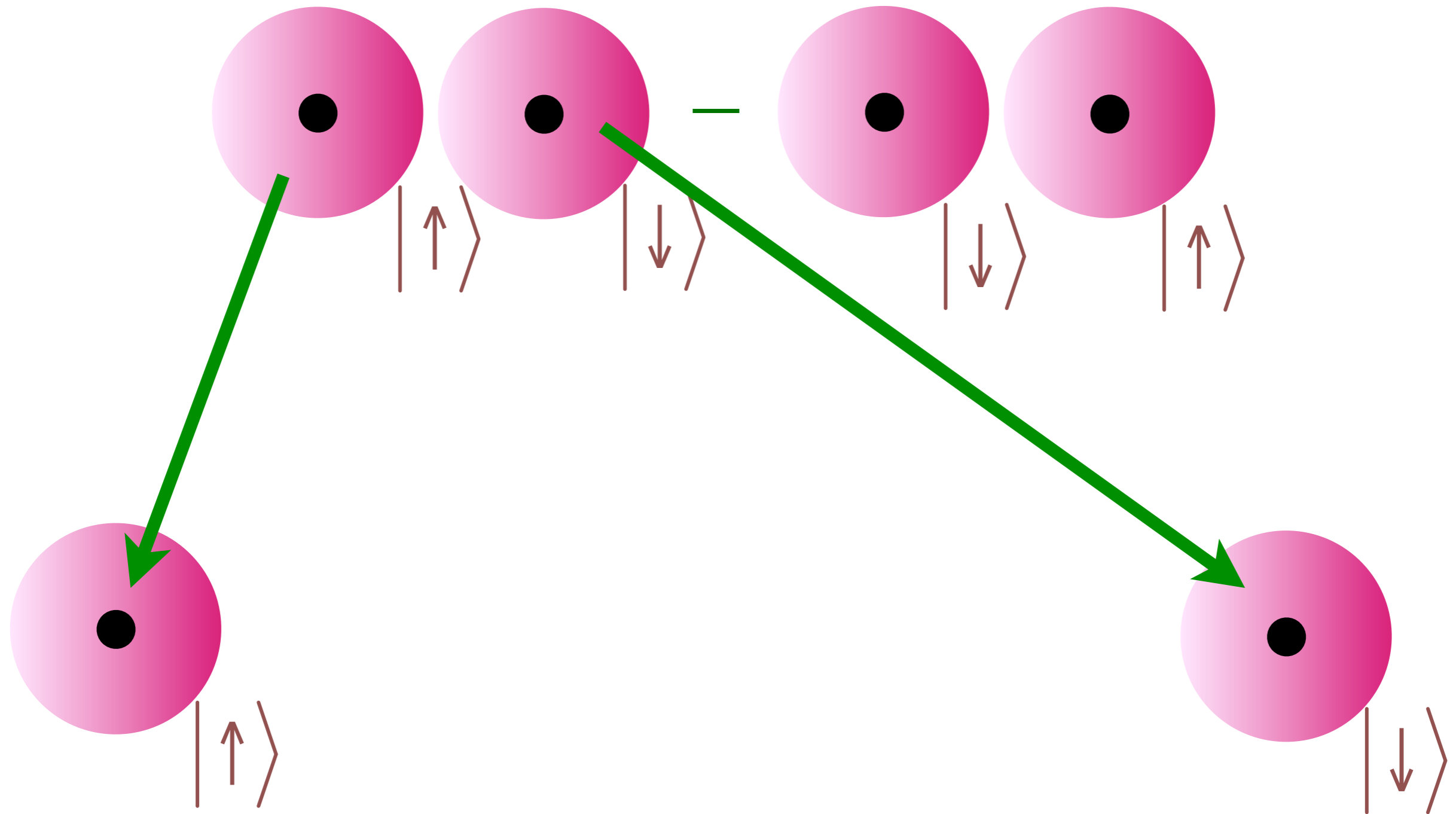
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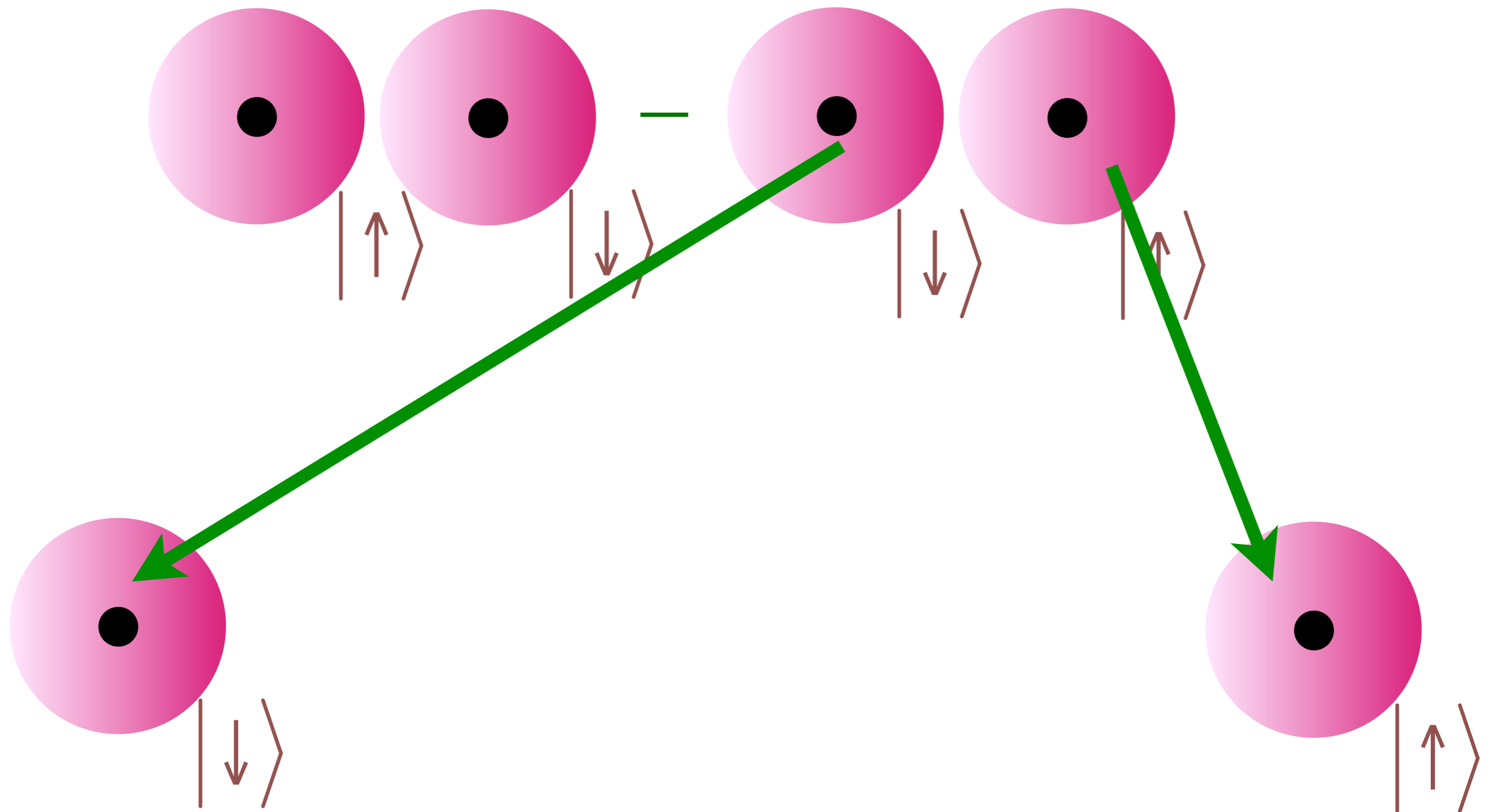
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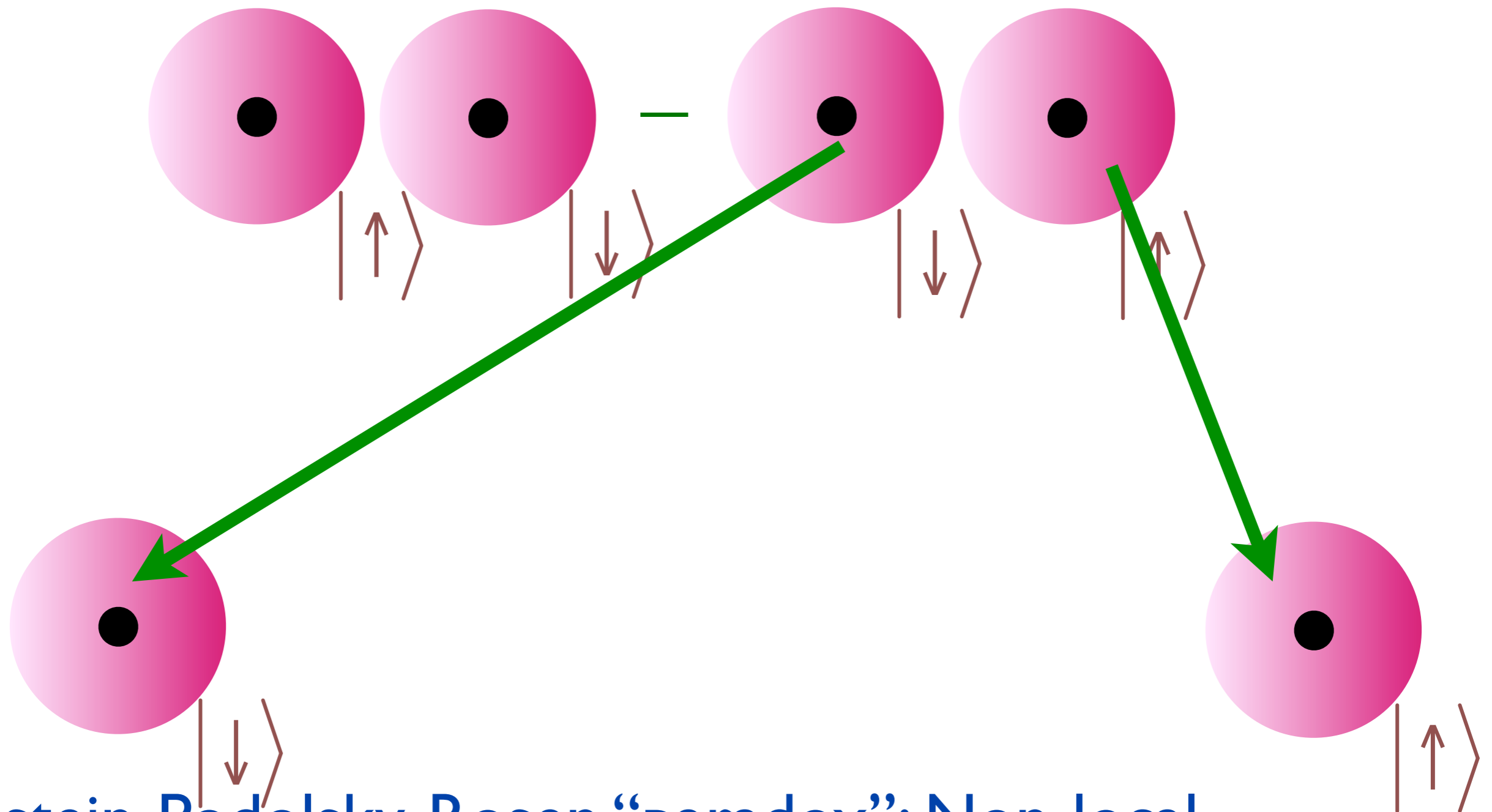
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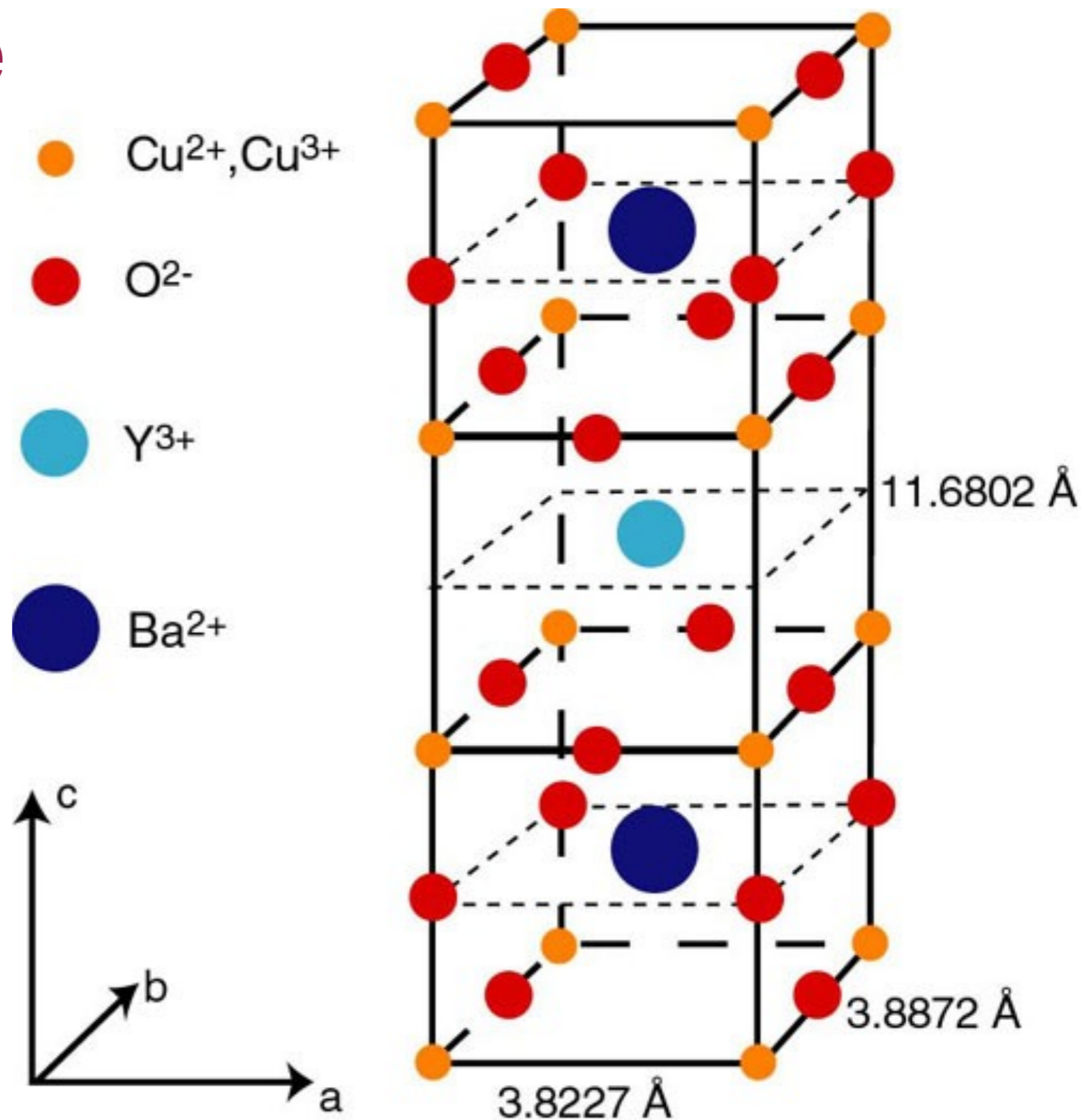
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Quantum Entanglement: quantum superposition with more than one particle

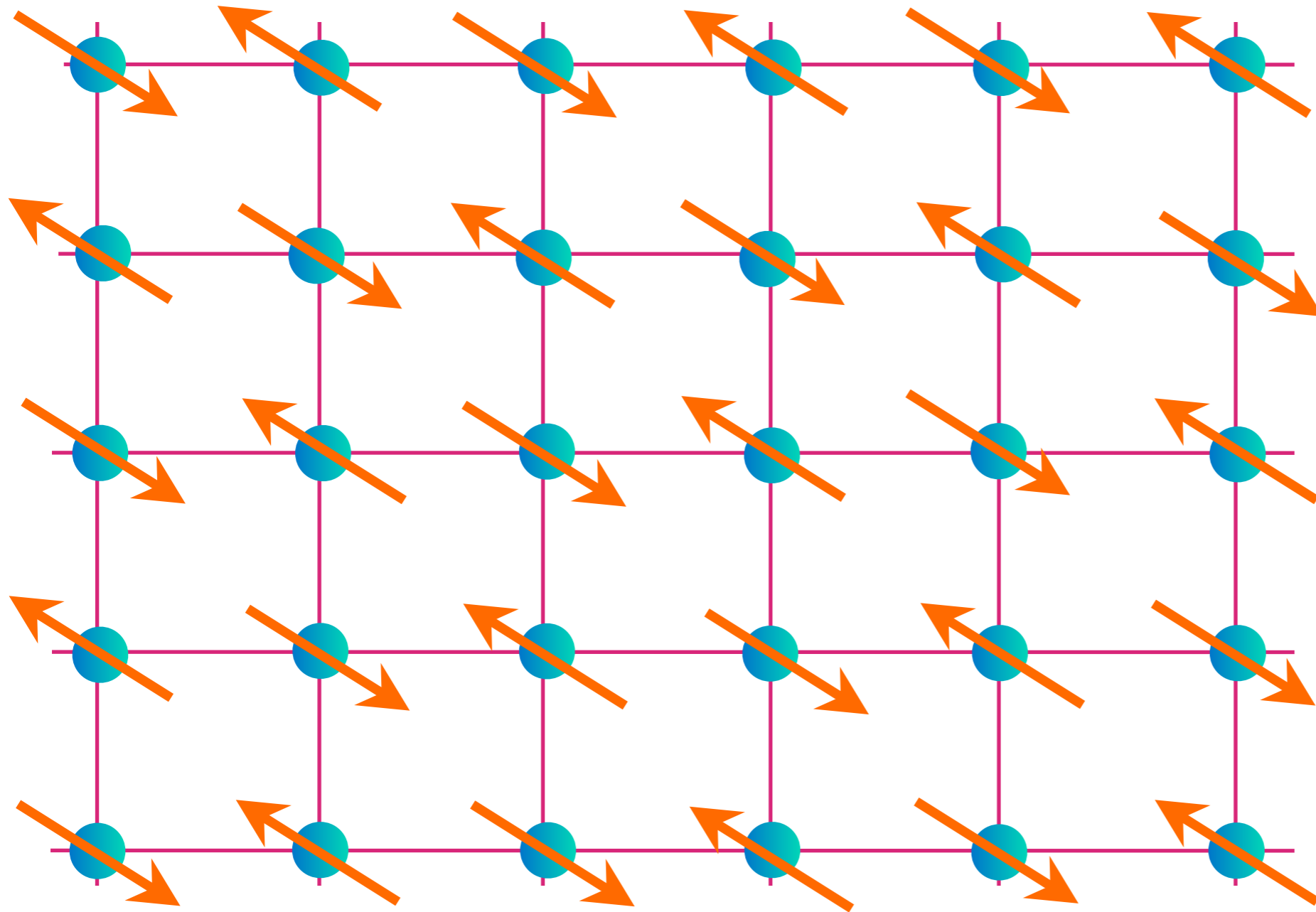


Einstein-Podolsky-Rosen “paradox”: Non-local correlations between observations arbitrarily far apart

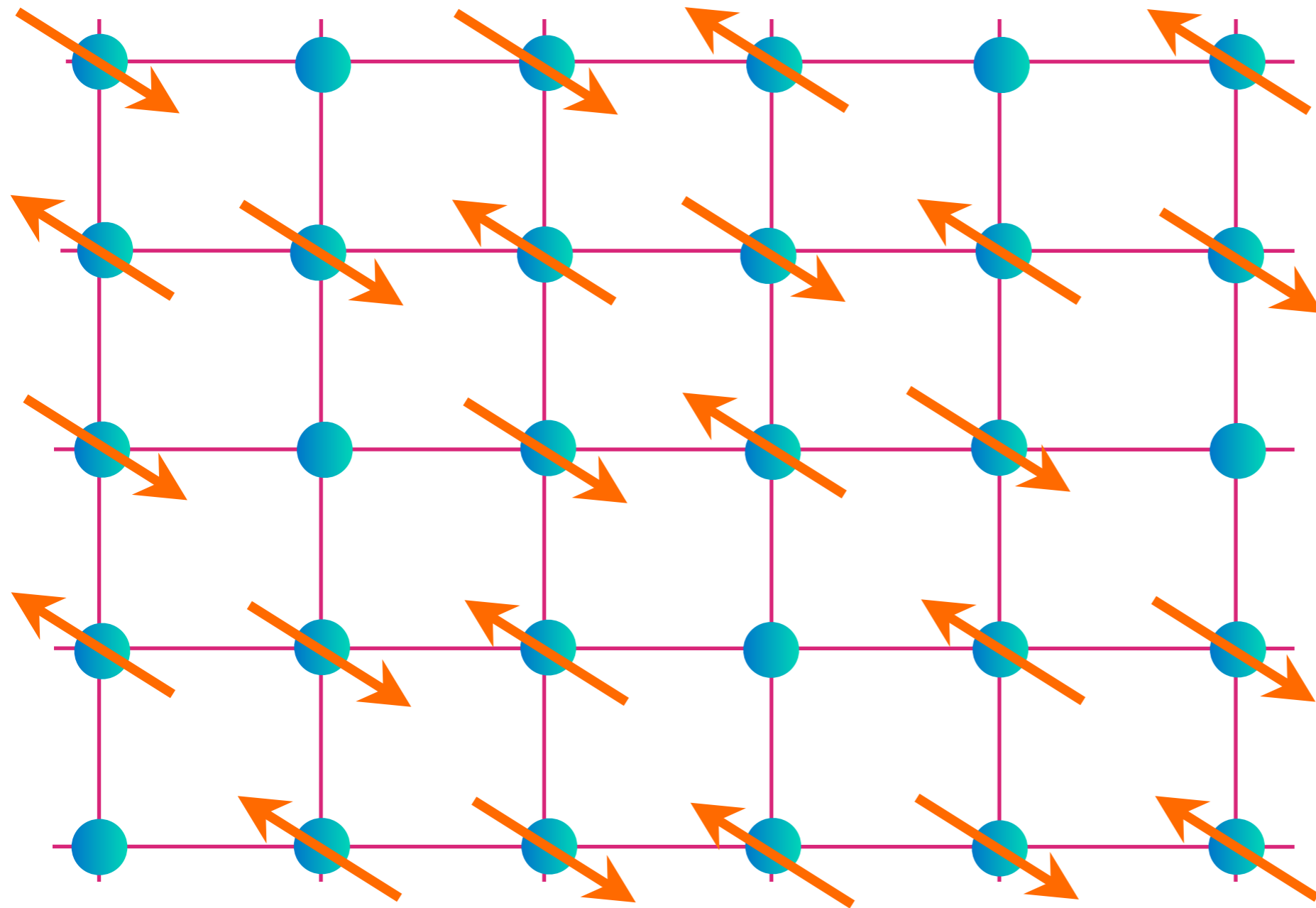
High temperature superconductors



Square lattice of Cu sites

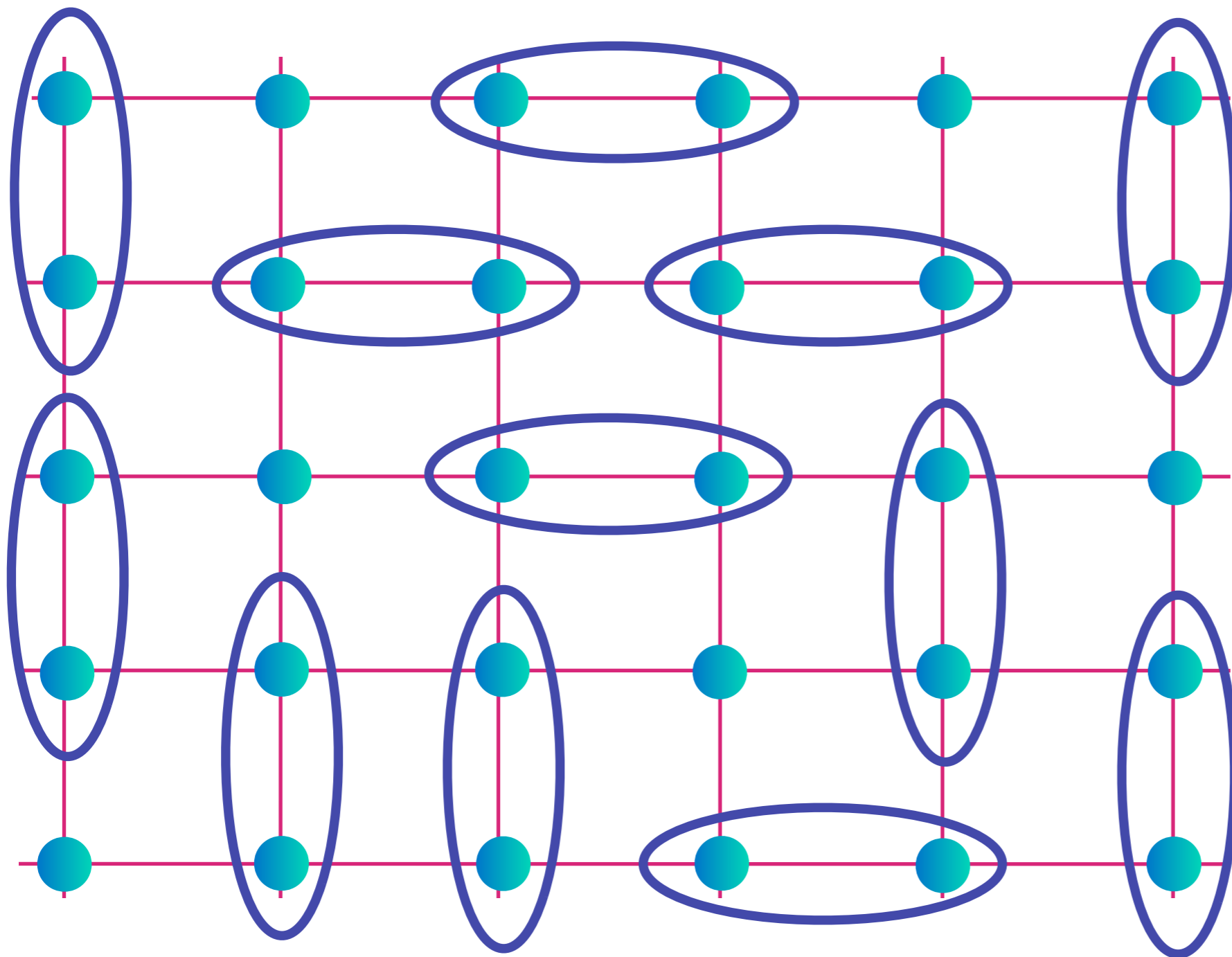


Square lattice of Cu sites



I. Remove
some electrons

Square lattice of Cu sites

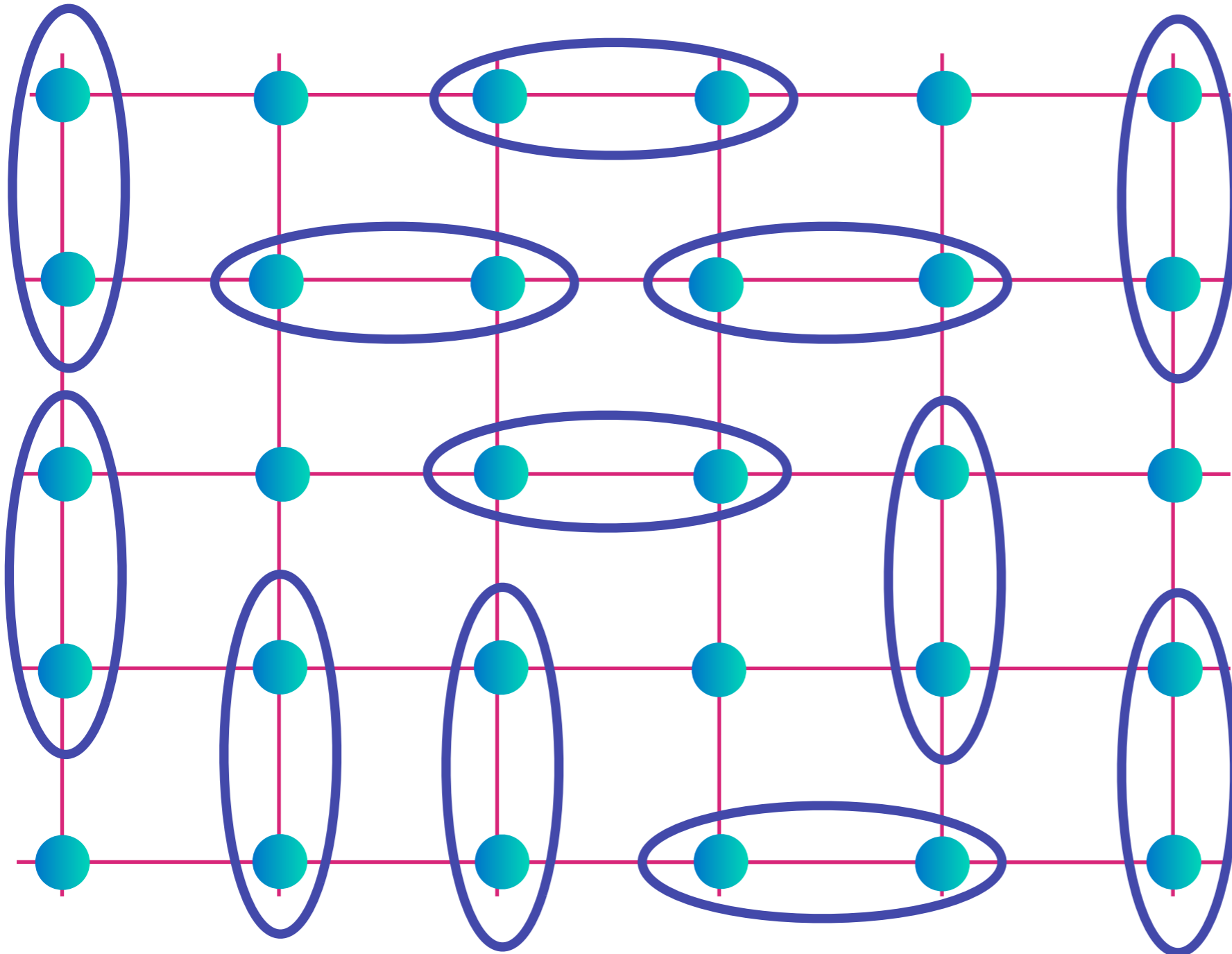


1. Remove some electrons

2. Electrons entangle into chemical bonds

$$\text{[Diagram of two sites in a blue oval]} = |\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle$$

Square lattice of Cu sites



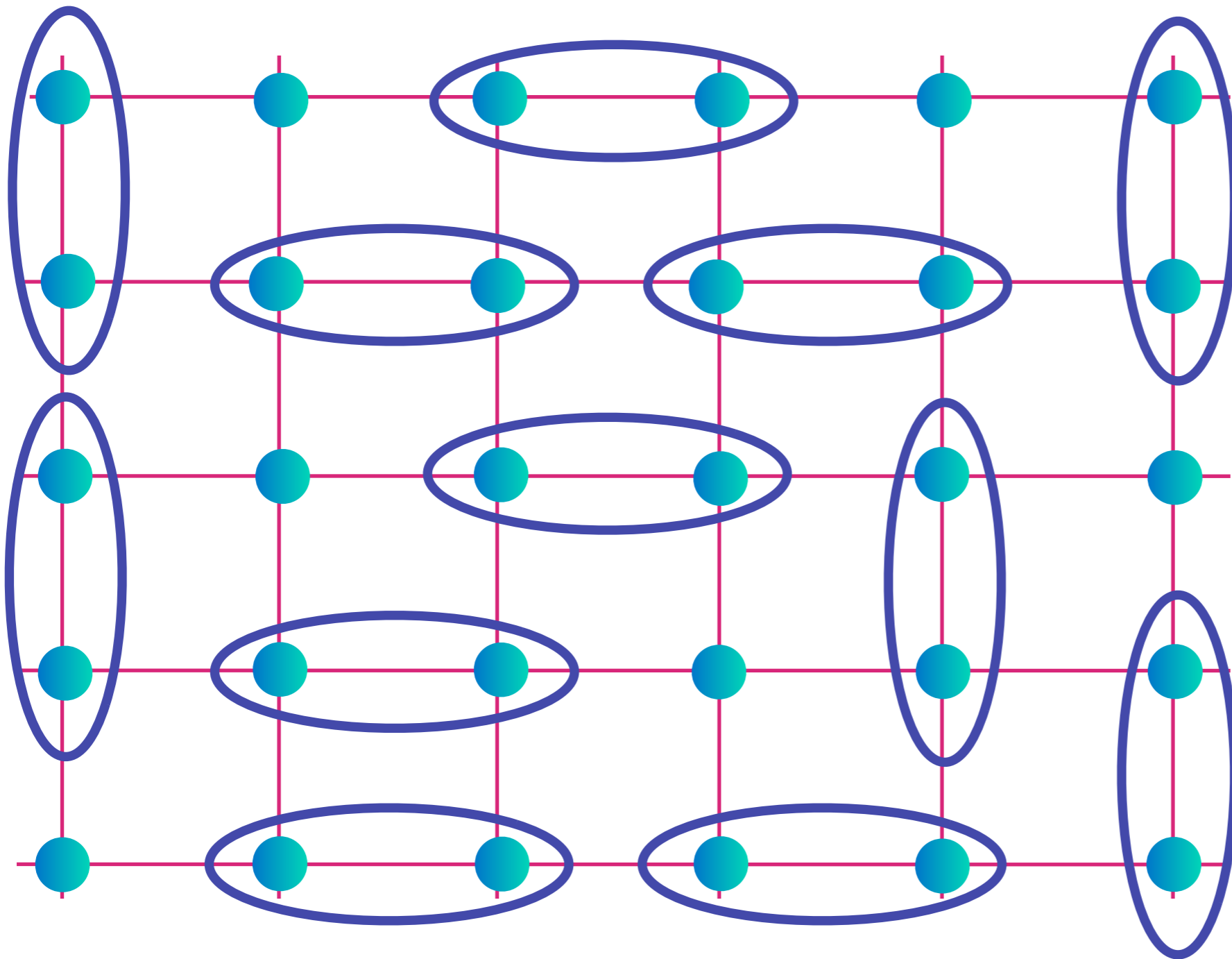
1. Remove some electrons

2. Electrons entangle into chemical bonds

3. Chemical bonds undergo Bose-Einstein condensation

$$\text{[Diagram of two teal dots in a blue oval]} = |\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle$$

Square lattice of Cu sites



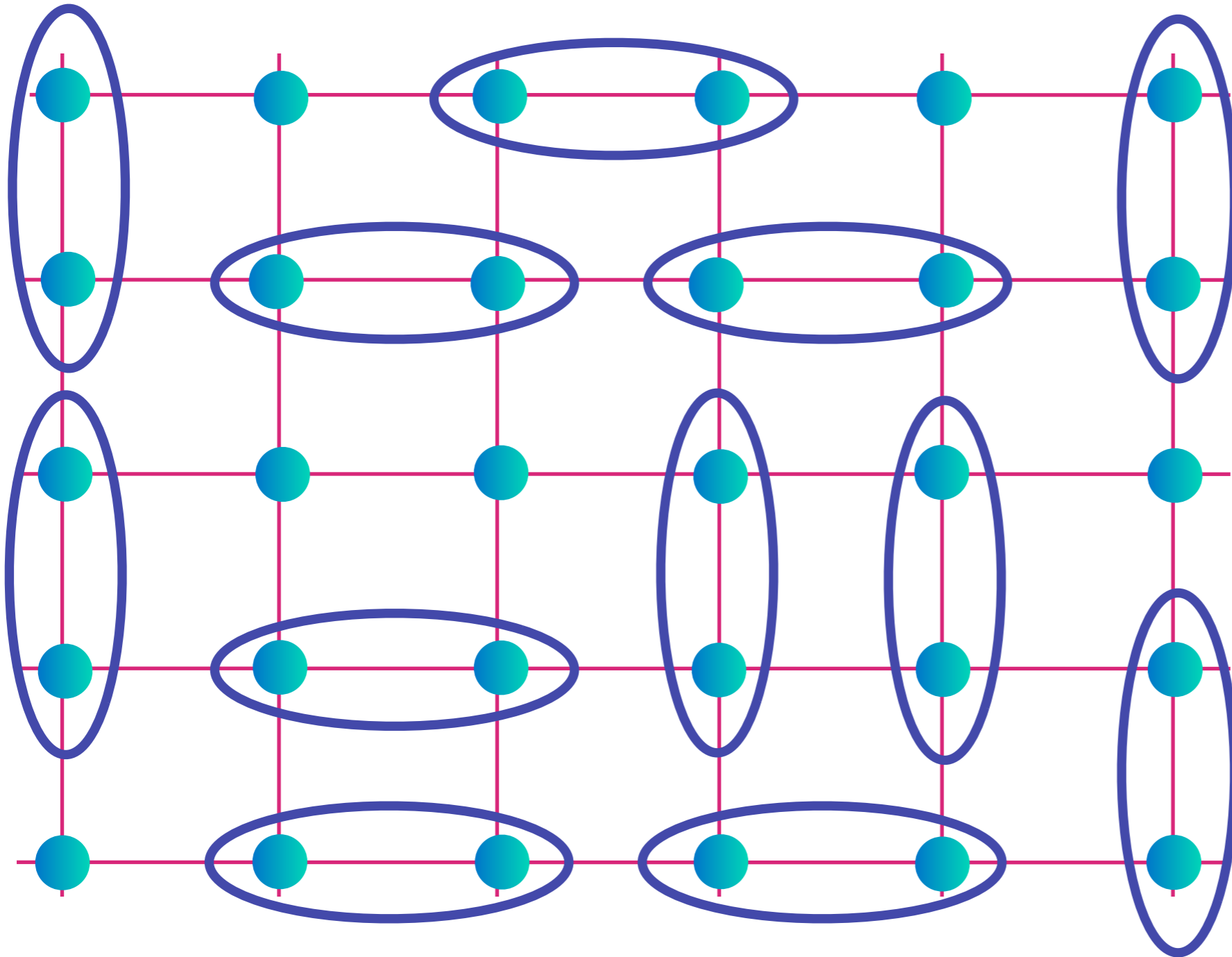
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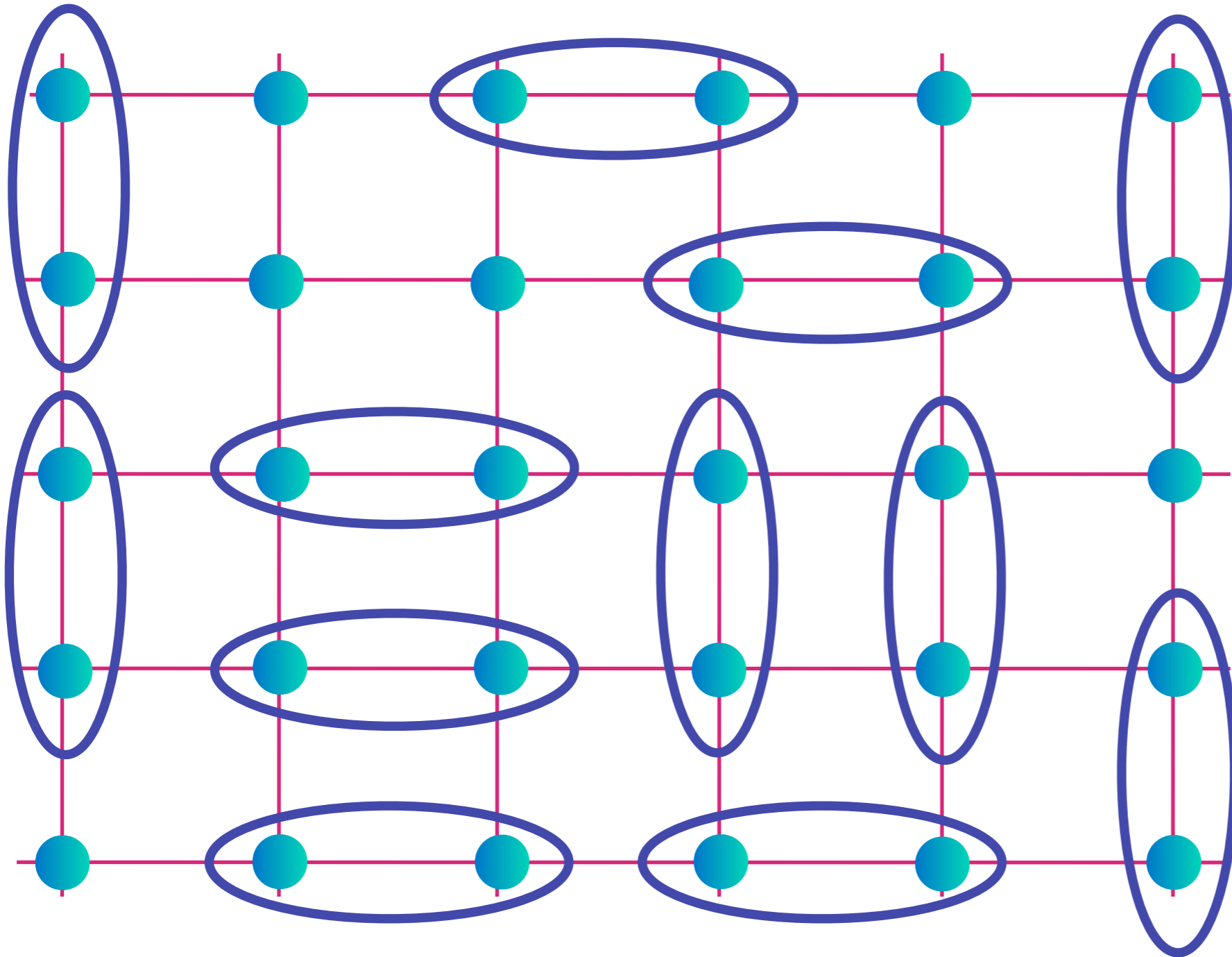
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$$\text{[Oval with two sites]} = |\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle$$

Square lattice of Cu sites



1. Remove some electrons

2. Electrons entangle into chemical bonds

3. Chemical bonds undergo Bose-Einstein condensation

$$\text{Bond} = |\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle$$