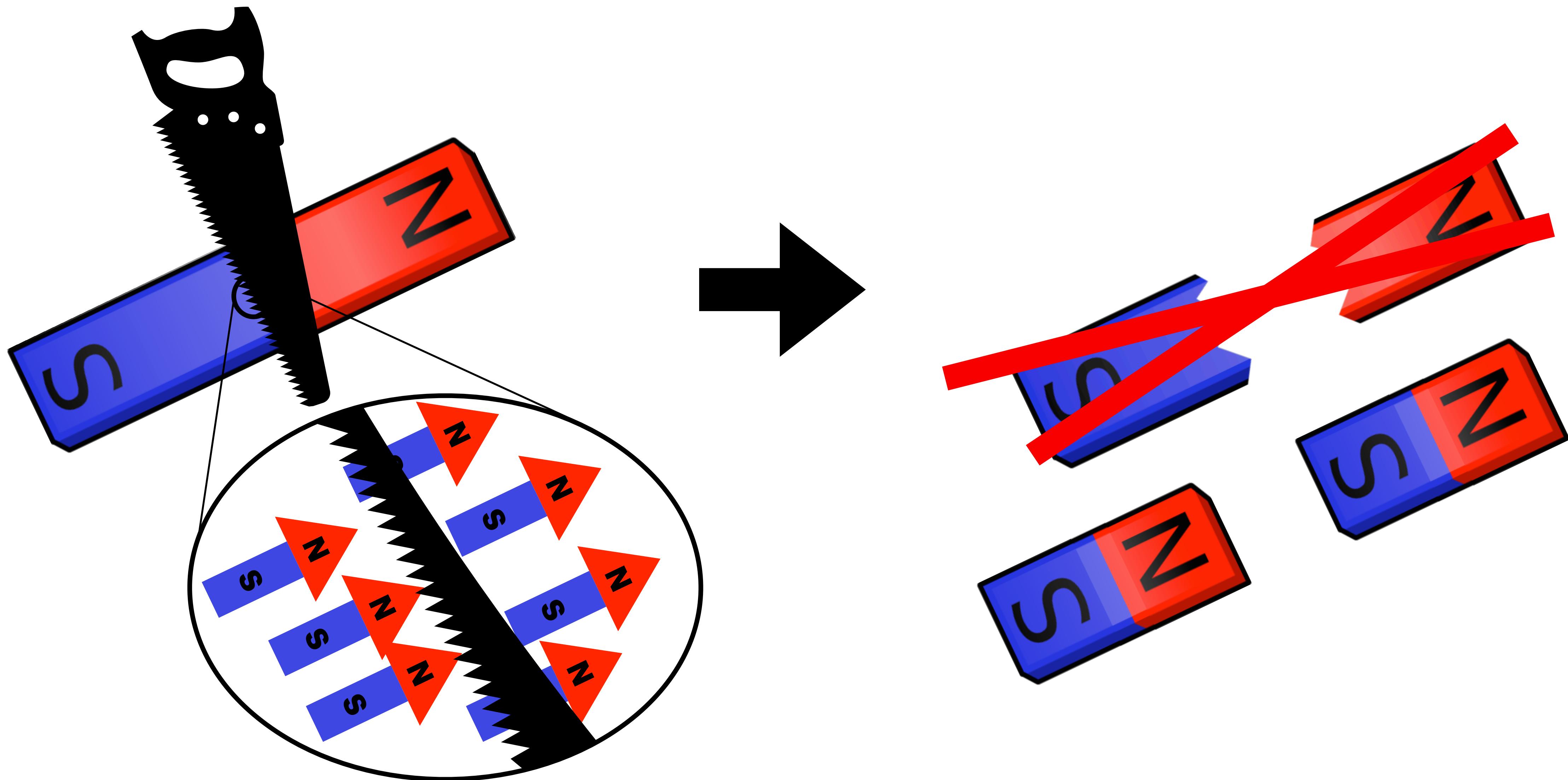


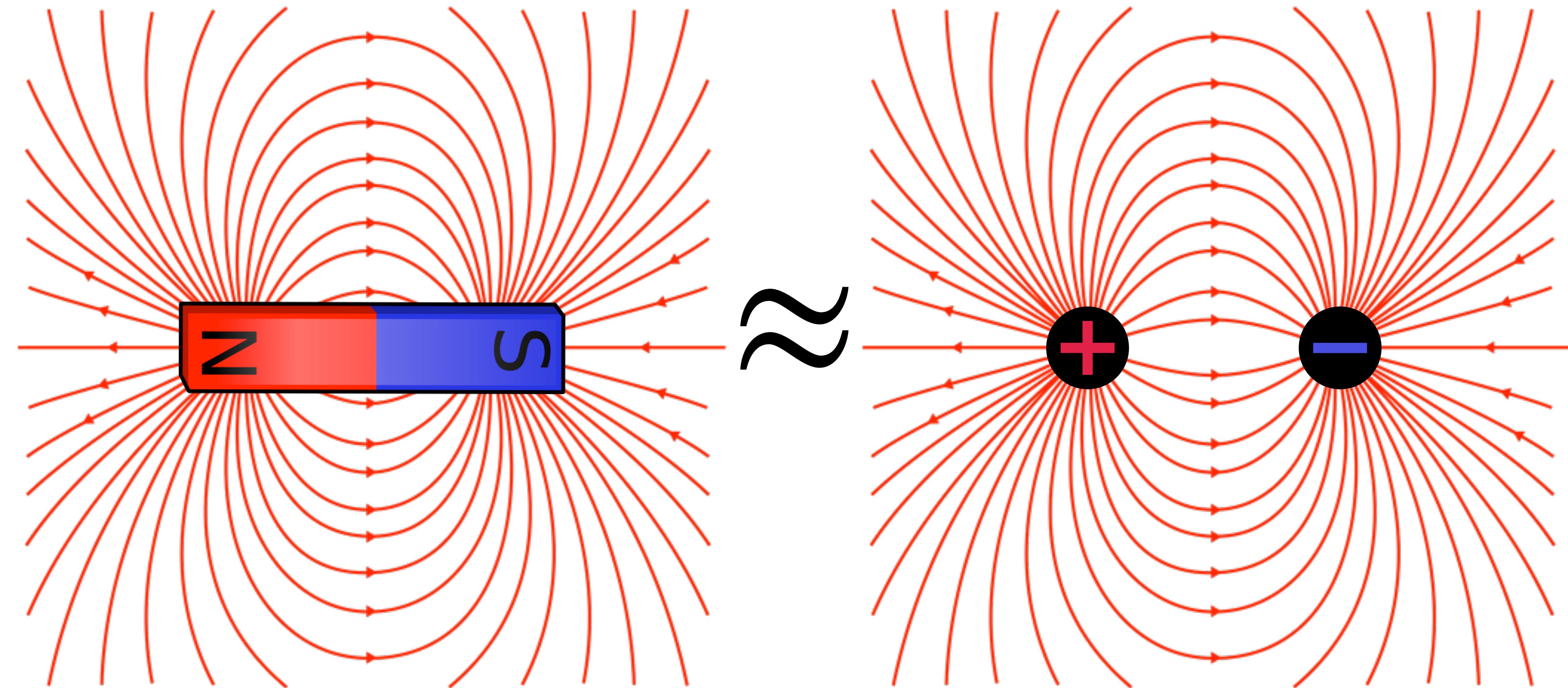
# Dividing the Indivisible

## Magnetism, Quantum Mechanics and the Origin of Matter

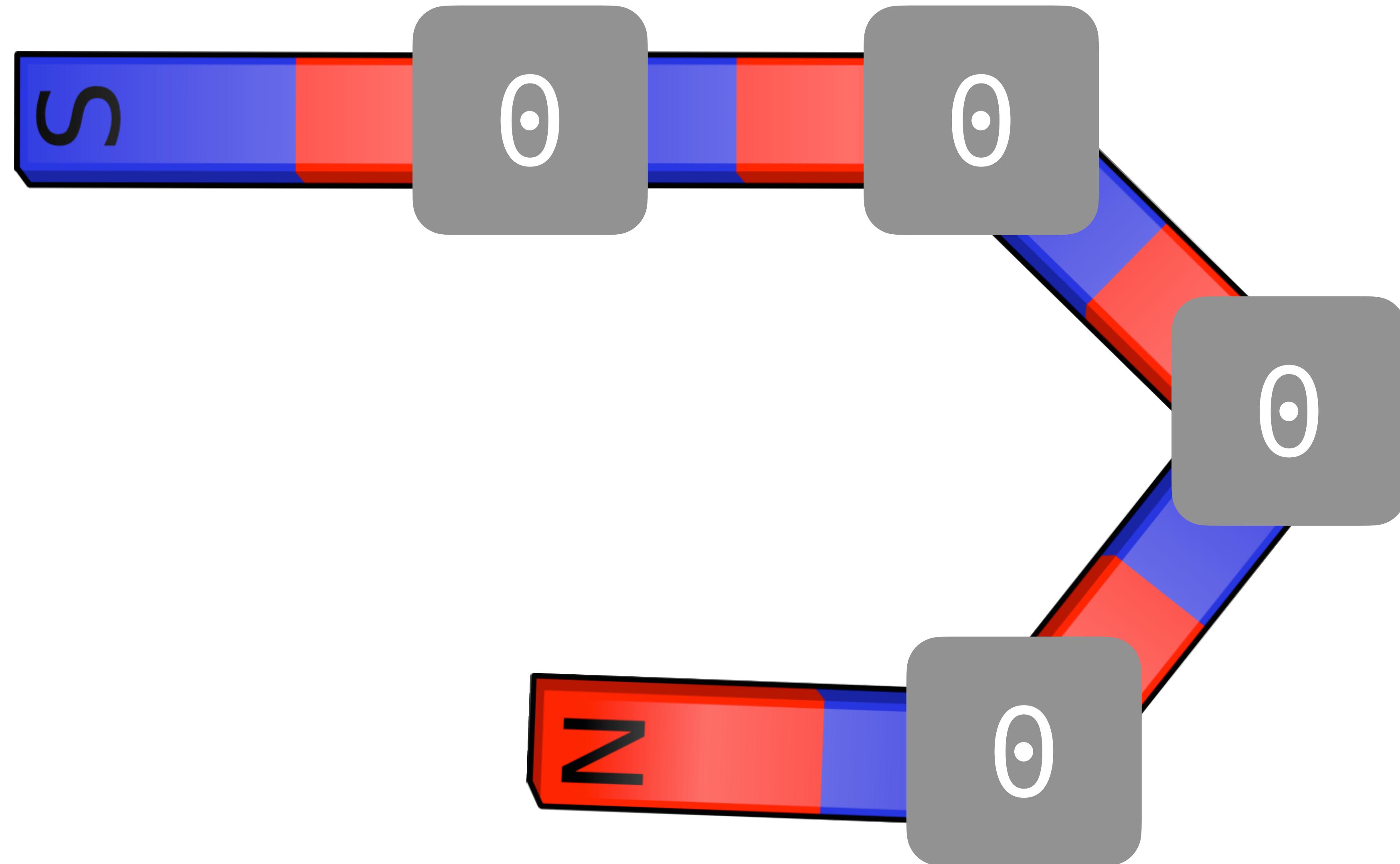
Alaric Sanders, 14/11/2023



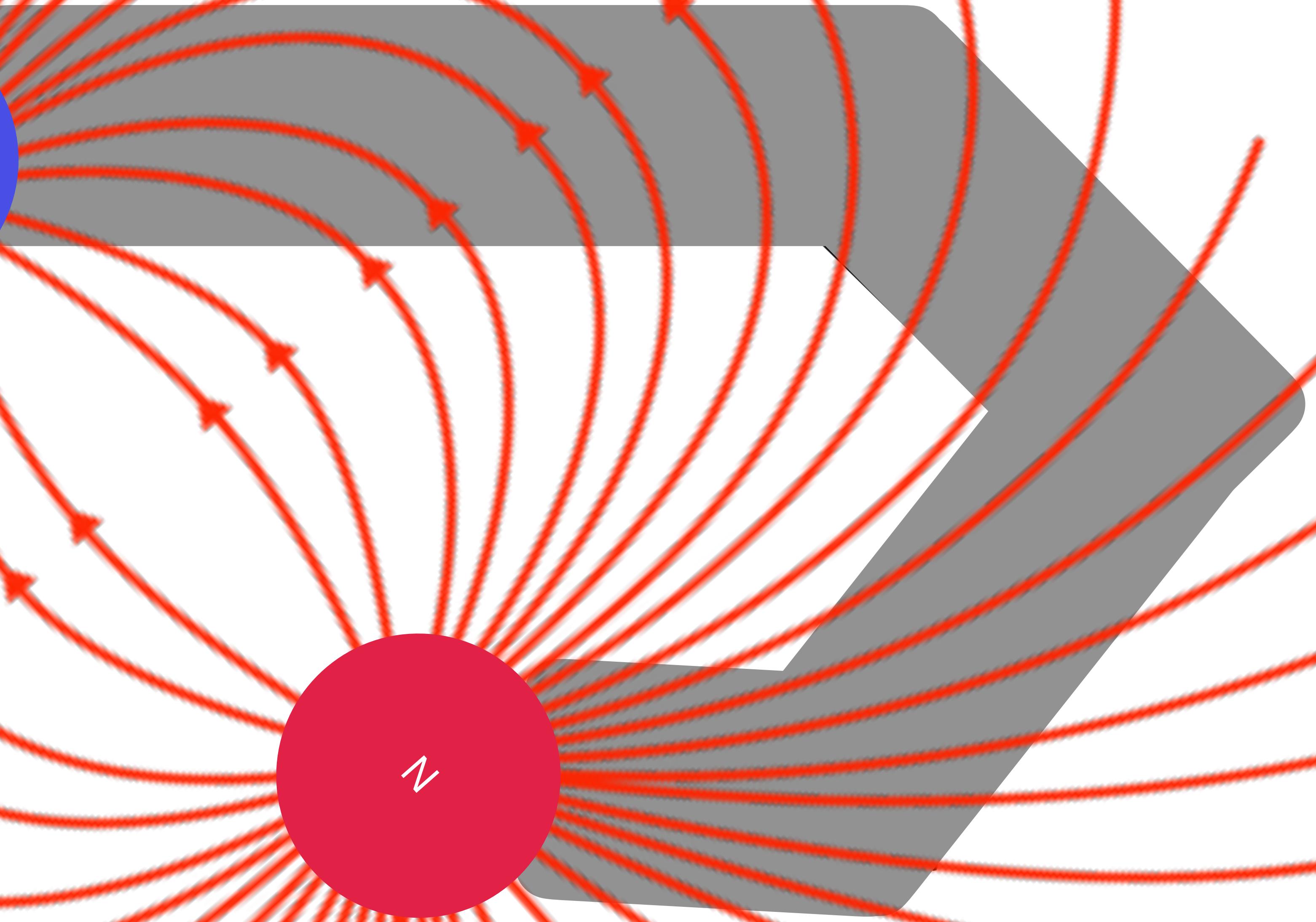
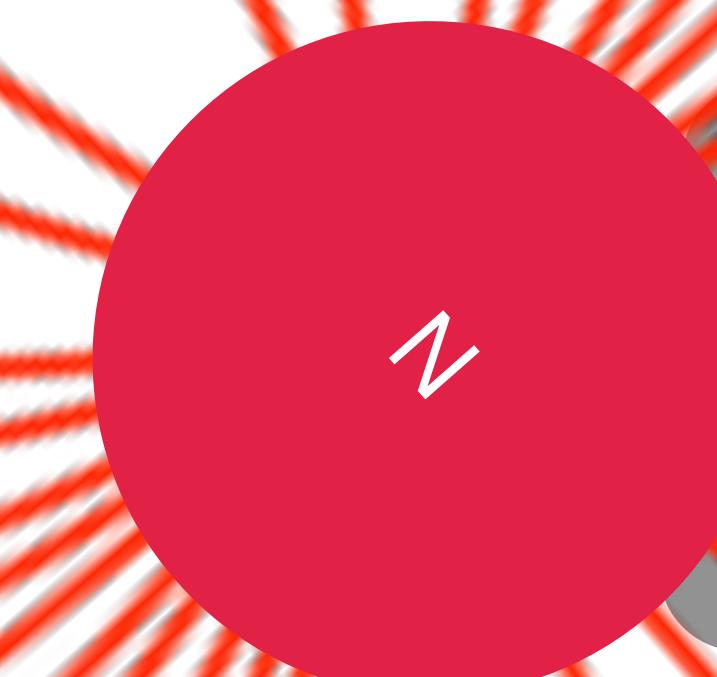
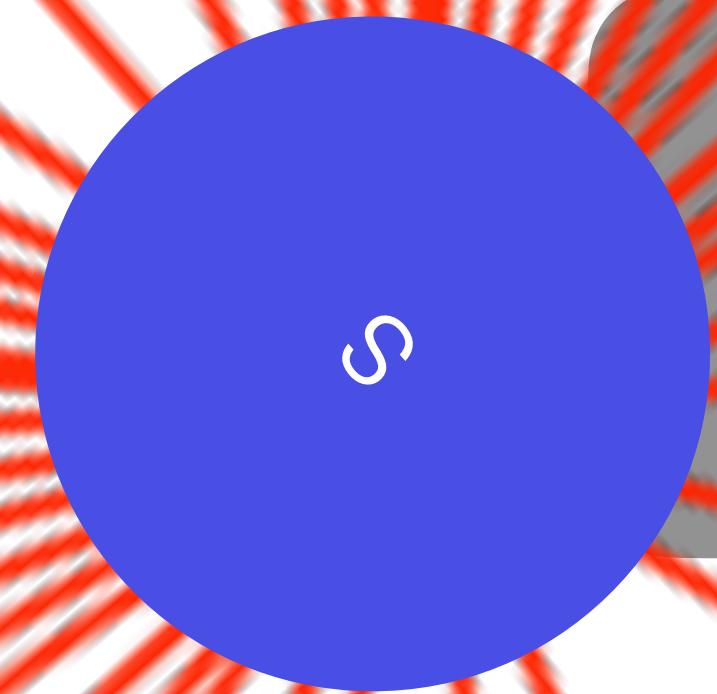
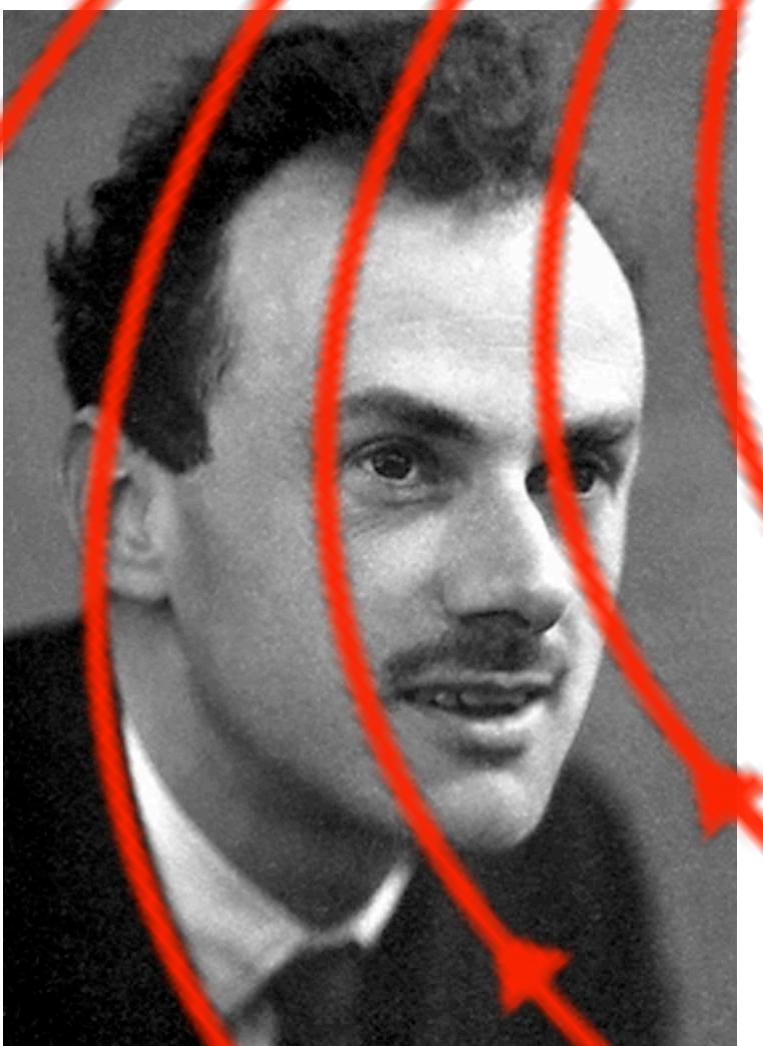
# A Dipole is like Two Monopoles



# Moving Monopoles by Cancellation

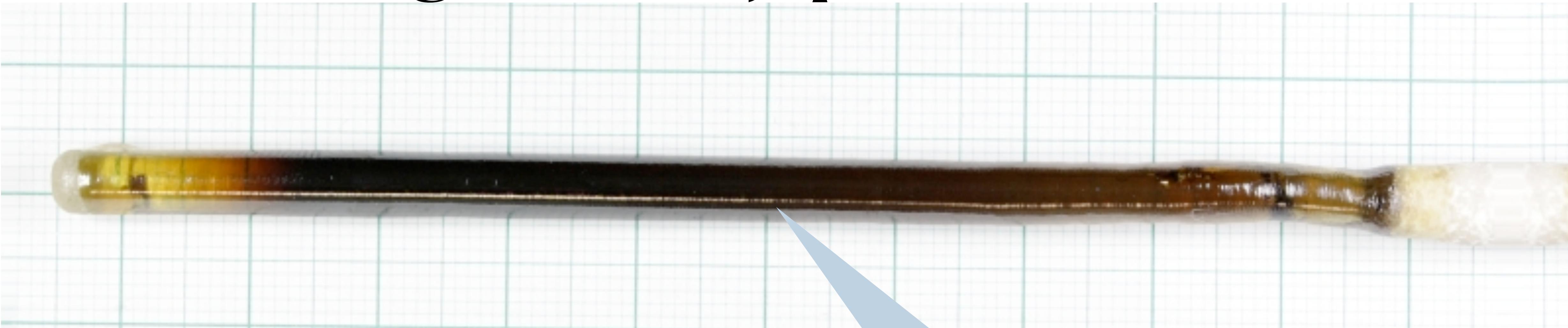


P.A.M. Dirac, 1902-1984

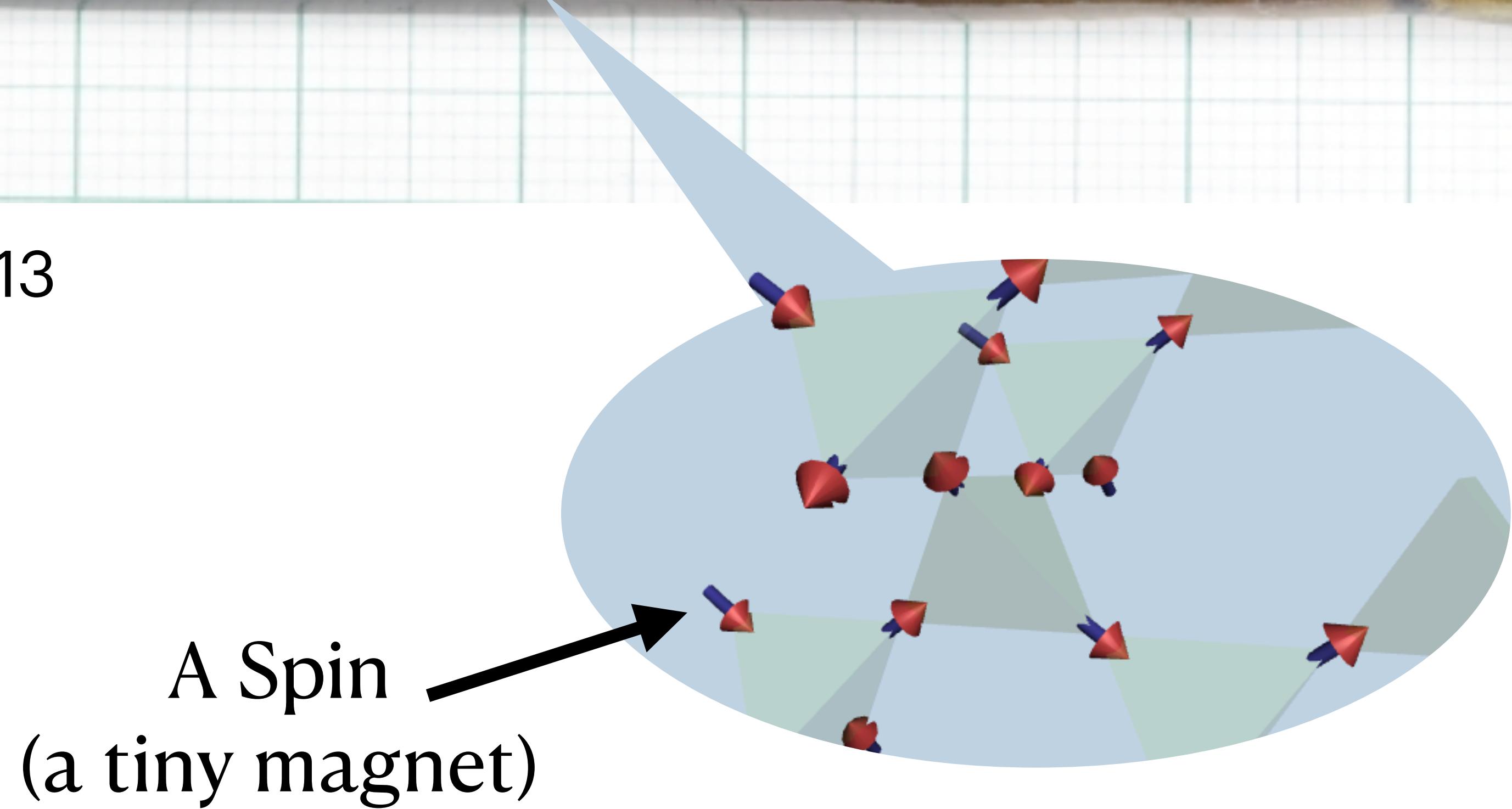


P.A.M. Dirac, 1902-1984

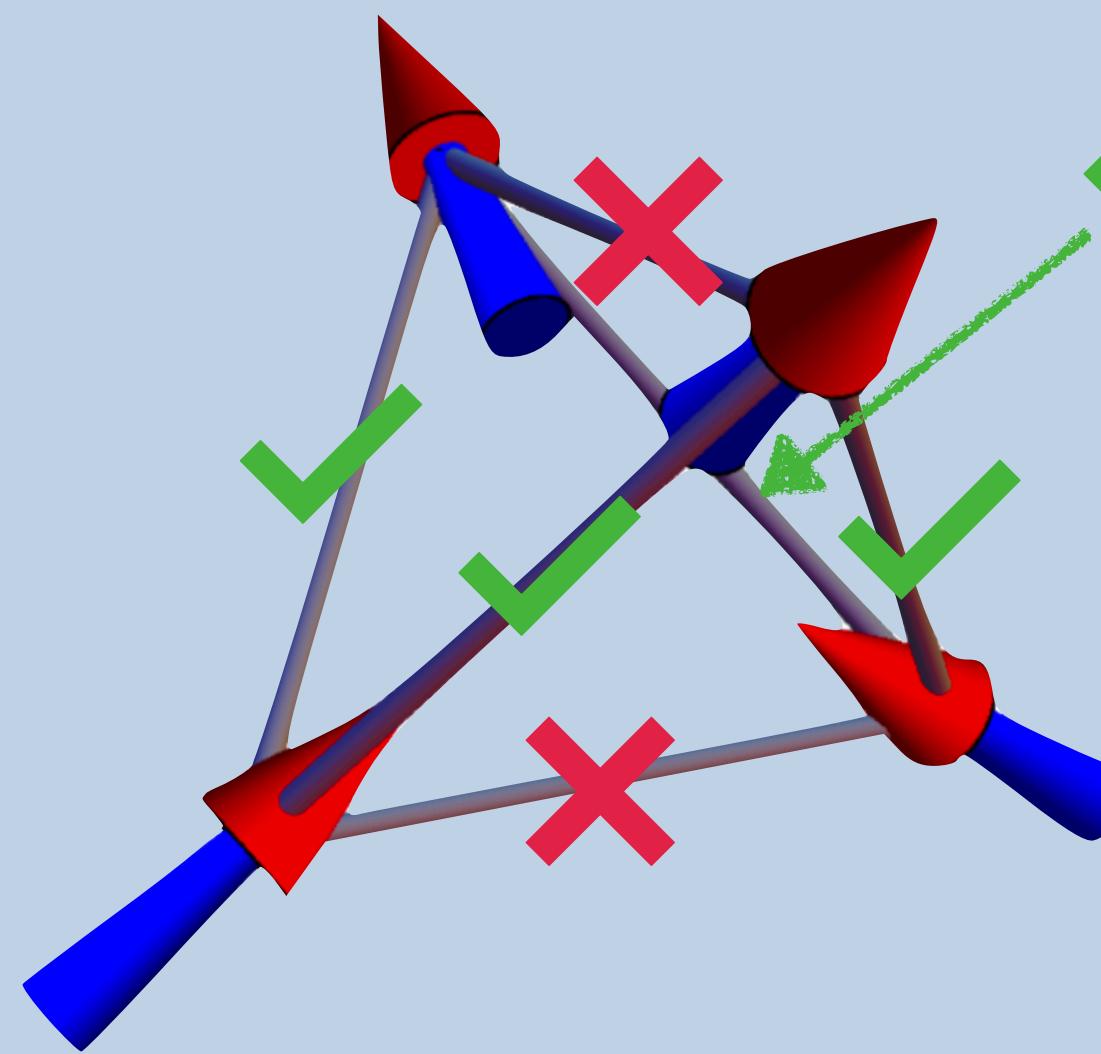
# Making it Real: Dysprosium Titanate



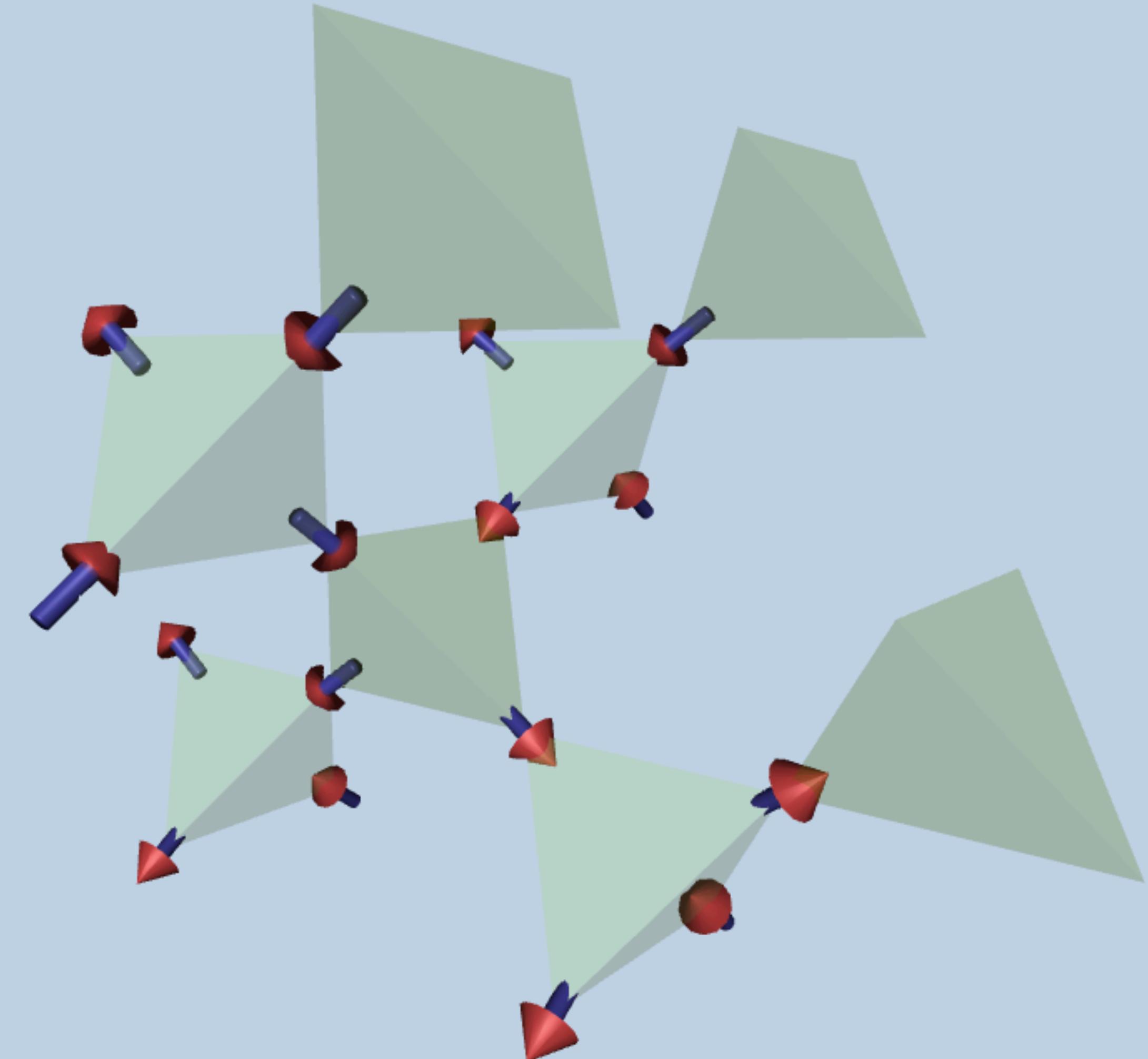
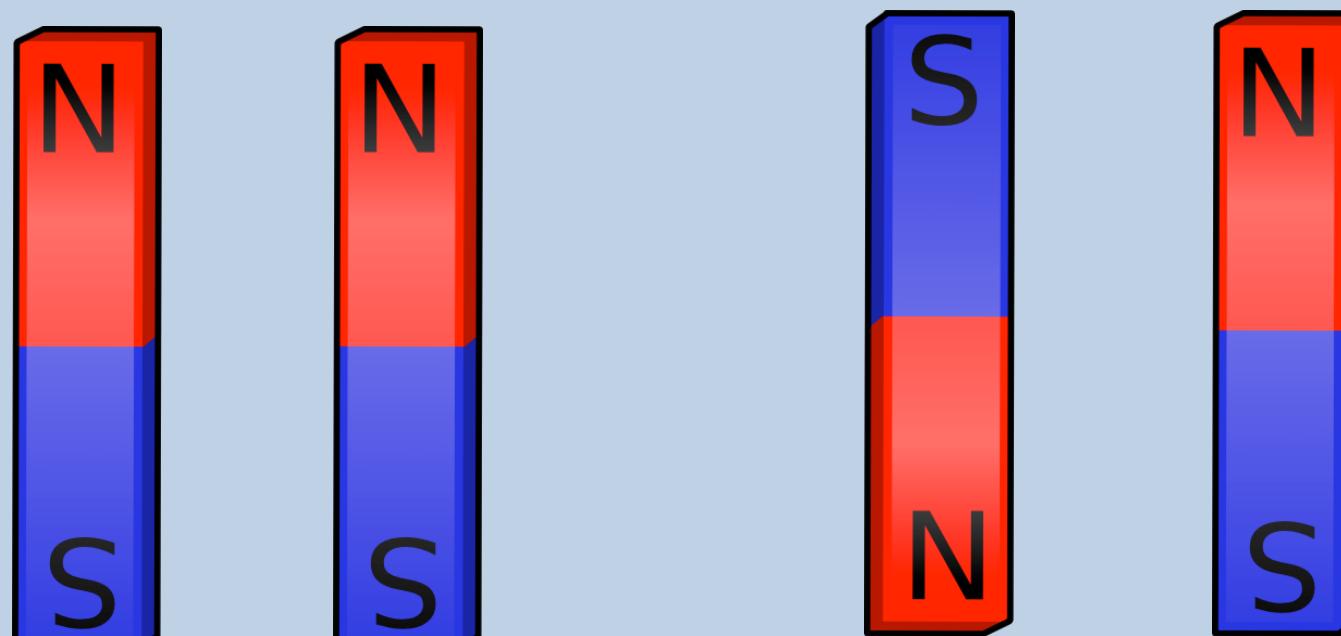
Timothy Munsie, 31 Oct 2013



# Magnetic Frustration



2 ✗/ tetrahedron



The Ice Rule: 2 in, 2 out

# Why “Ice”?

## THE JOURNAL OF CHEMICAL PHYSICS

VOLUME 1

AUGUST, 1933

NUMBER 8

A Theory of Water and Ionic Solution, with Particular Reference to Hydrogen and Hydroxyl Ions

J. D. BERNAL AND R. H. FOWLER, *University of Cambridge, England*

(Received April 29, 1933)

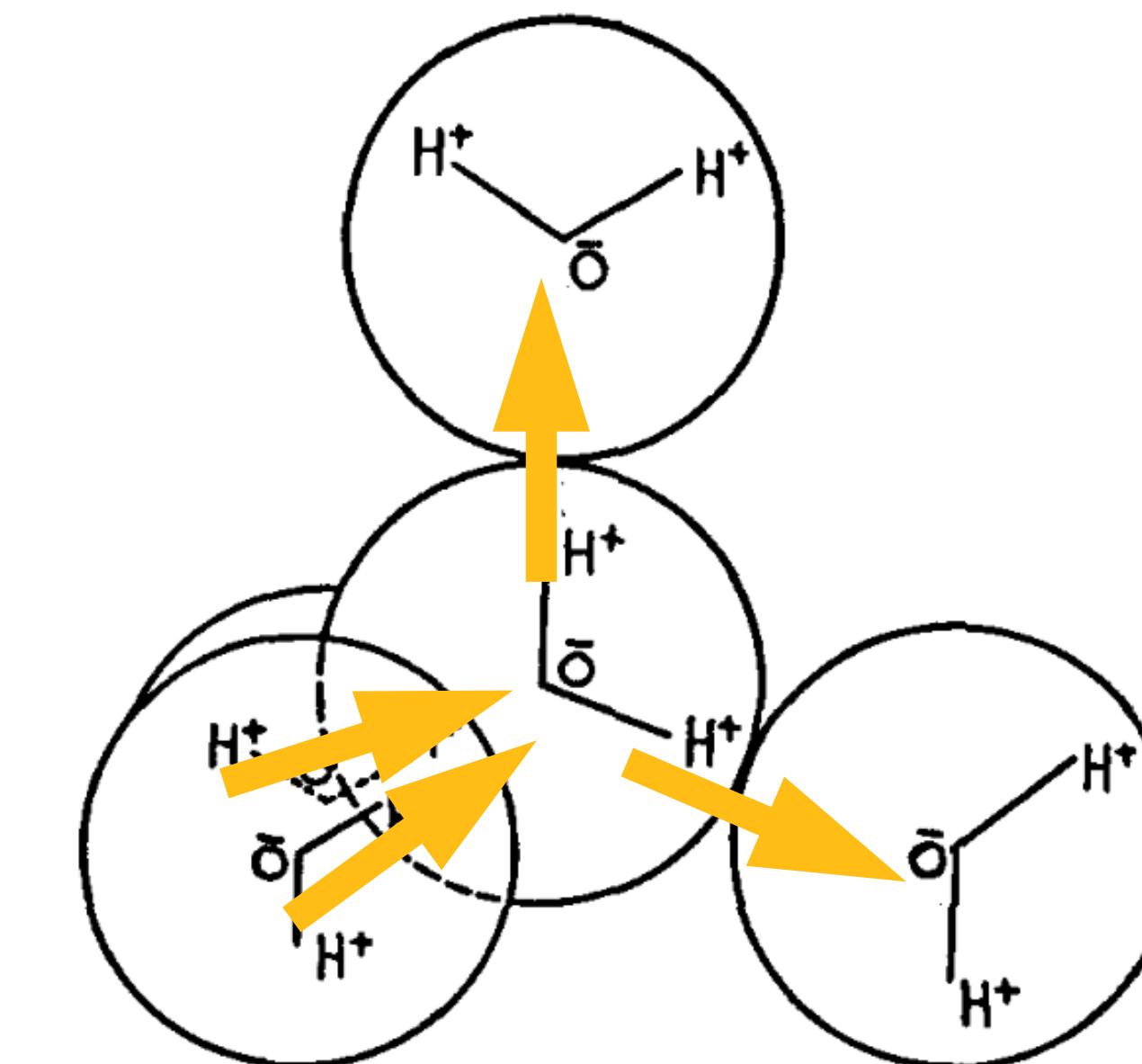
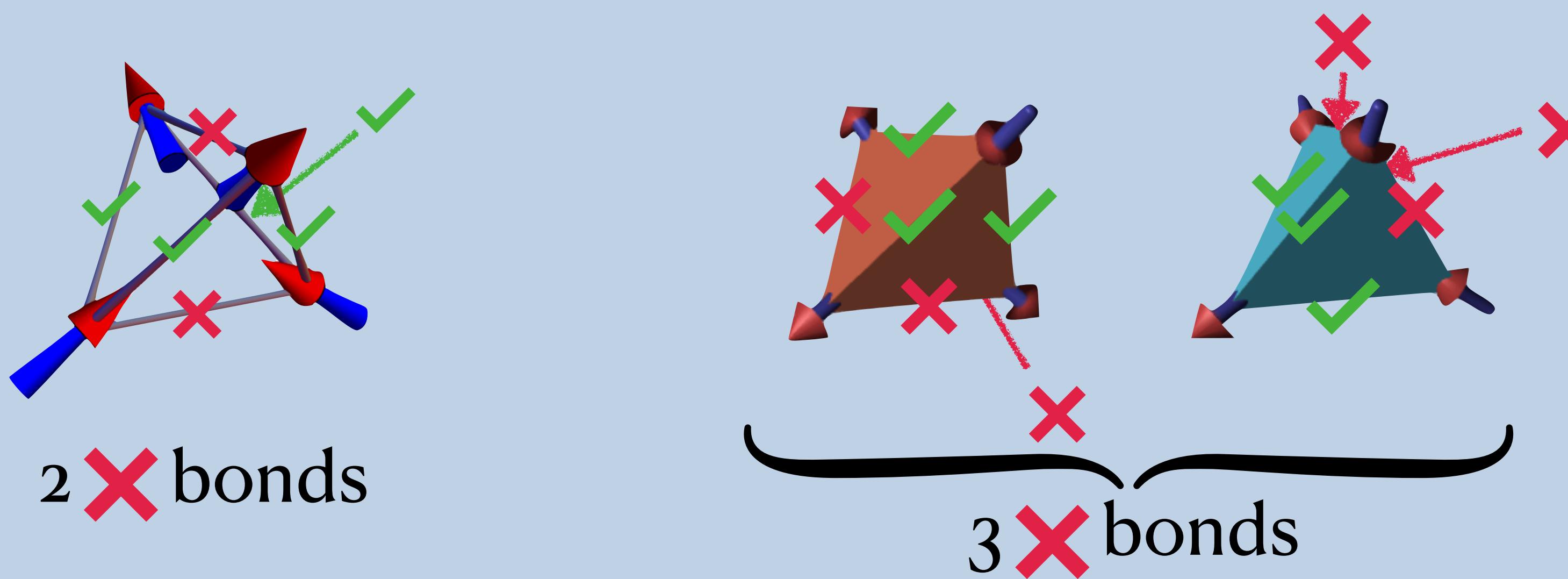
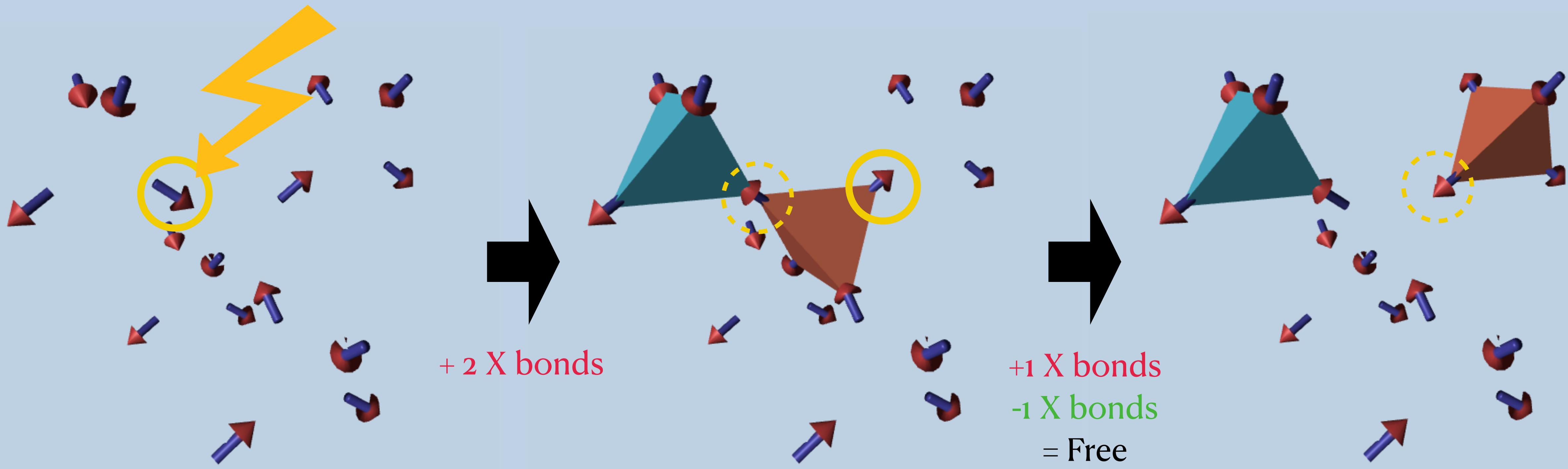
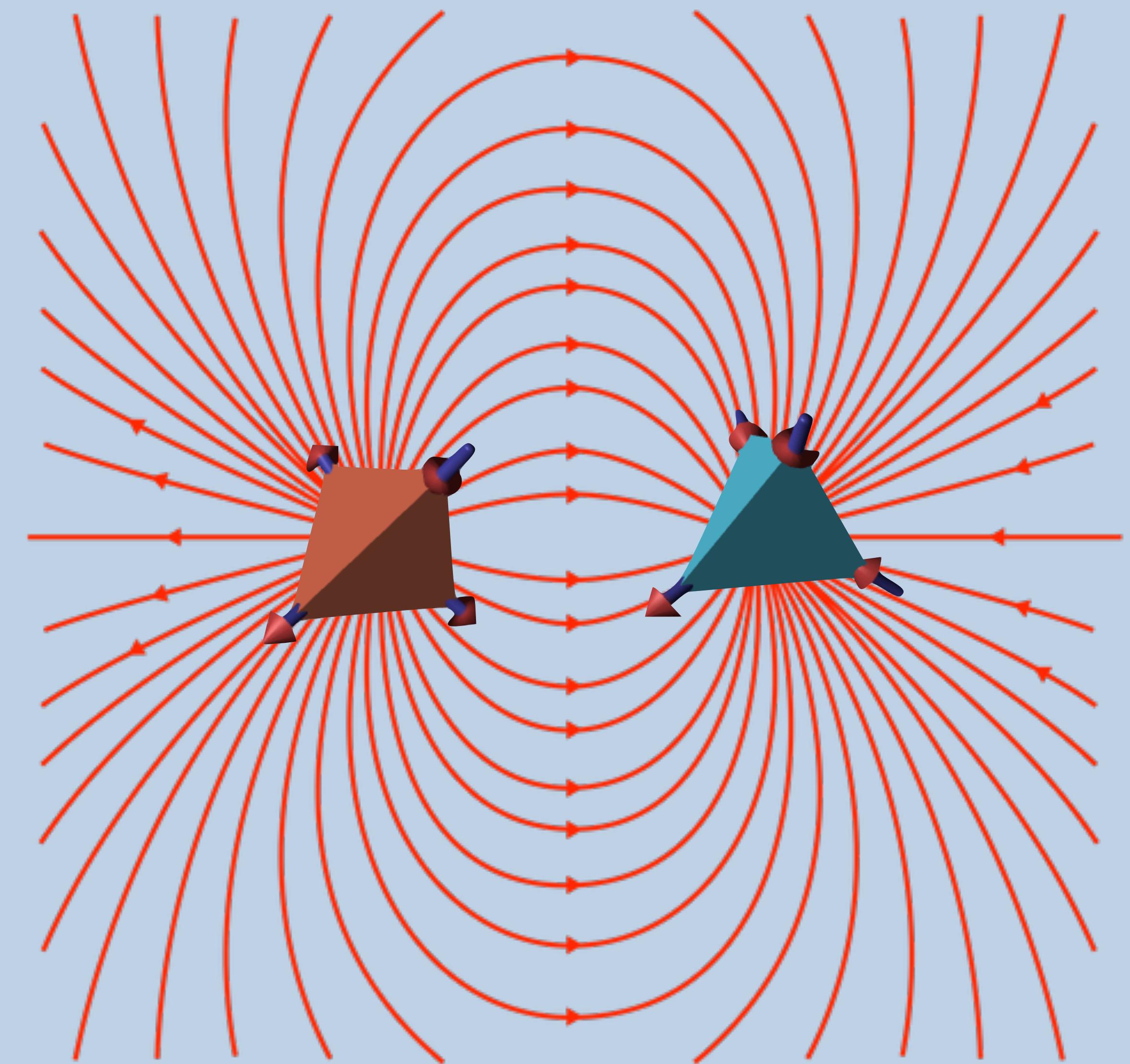
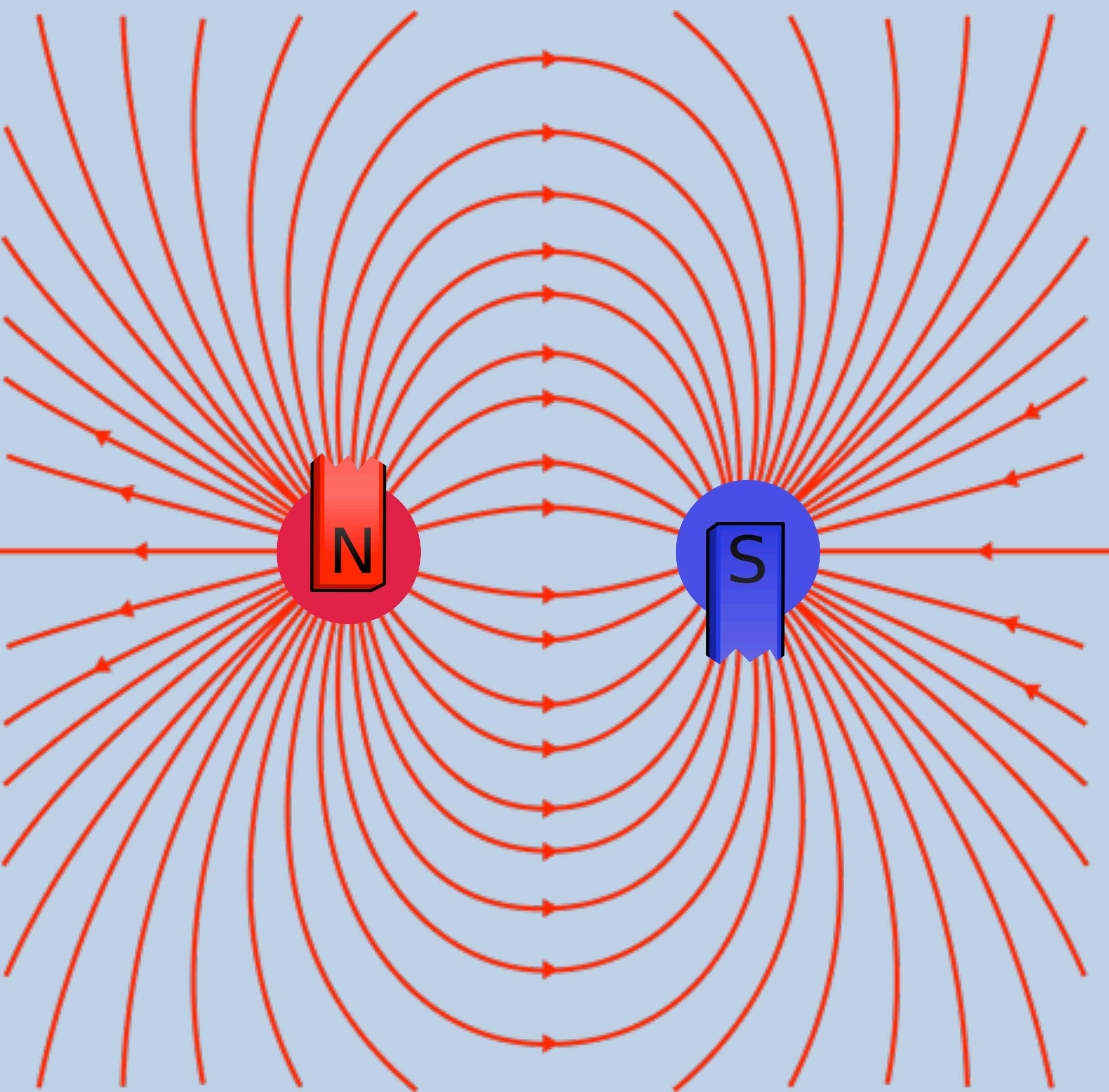


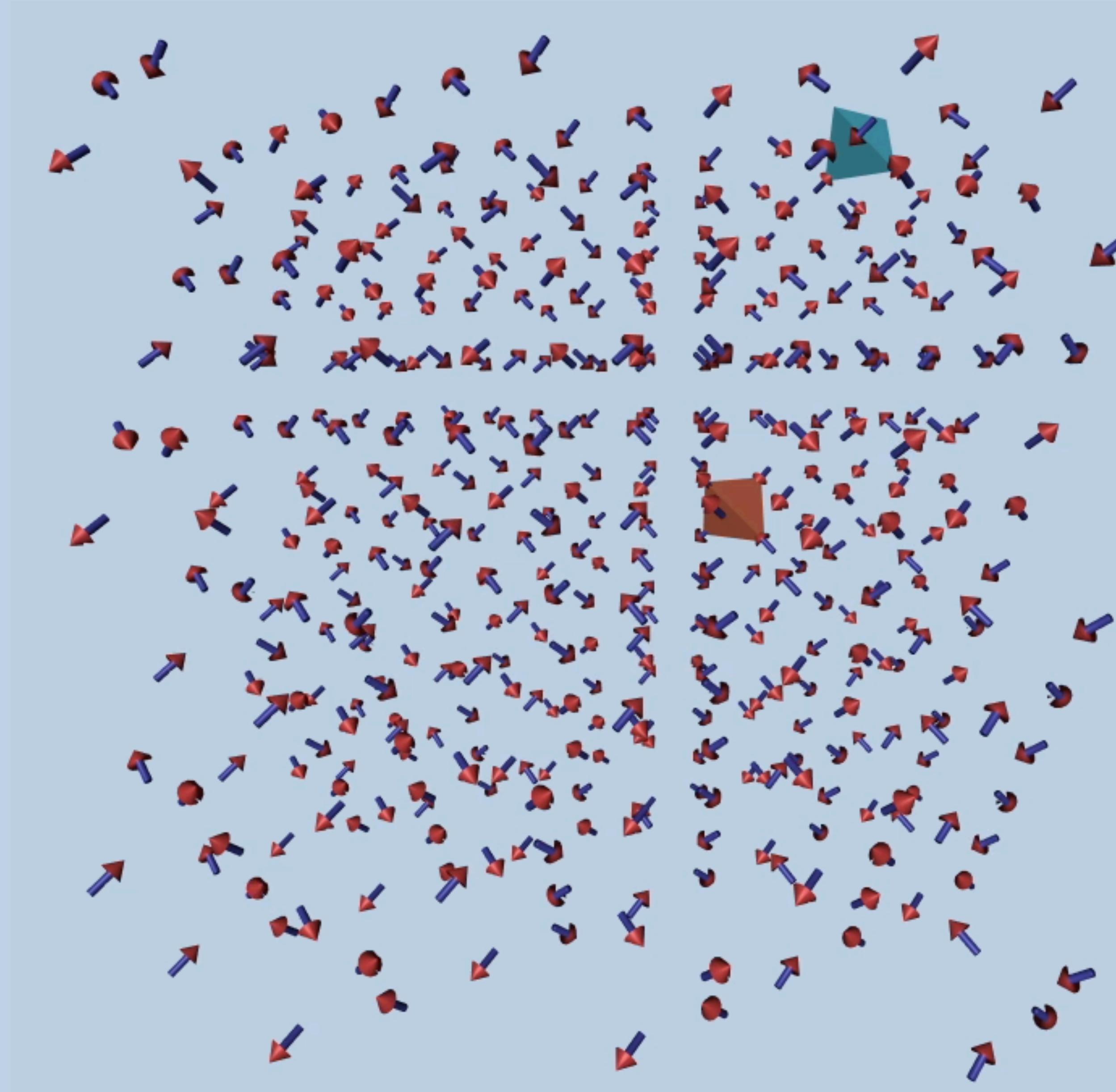
FIG. 4. Tetrahedral coordination of water molecules. The four molecules surrounding one water molecule are shown. Of these, two are in the plane of the paper, one above and one below it.





$\approx$

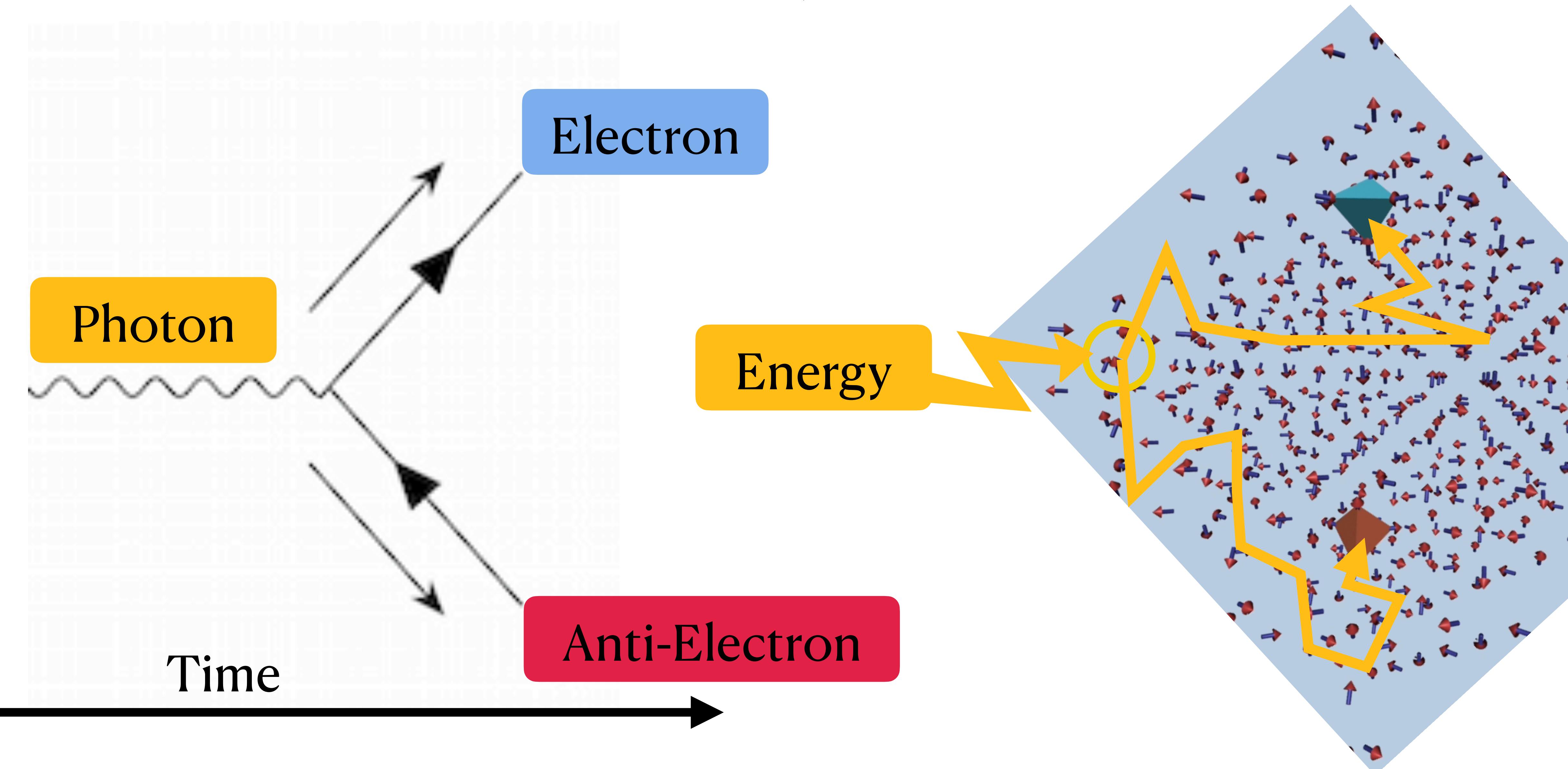


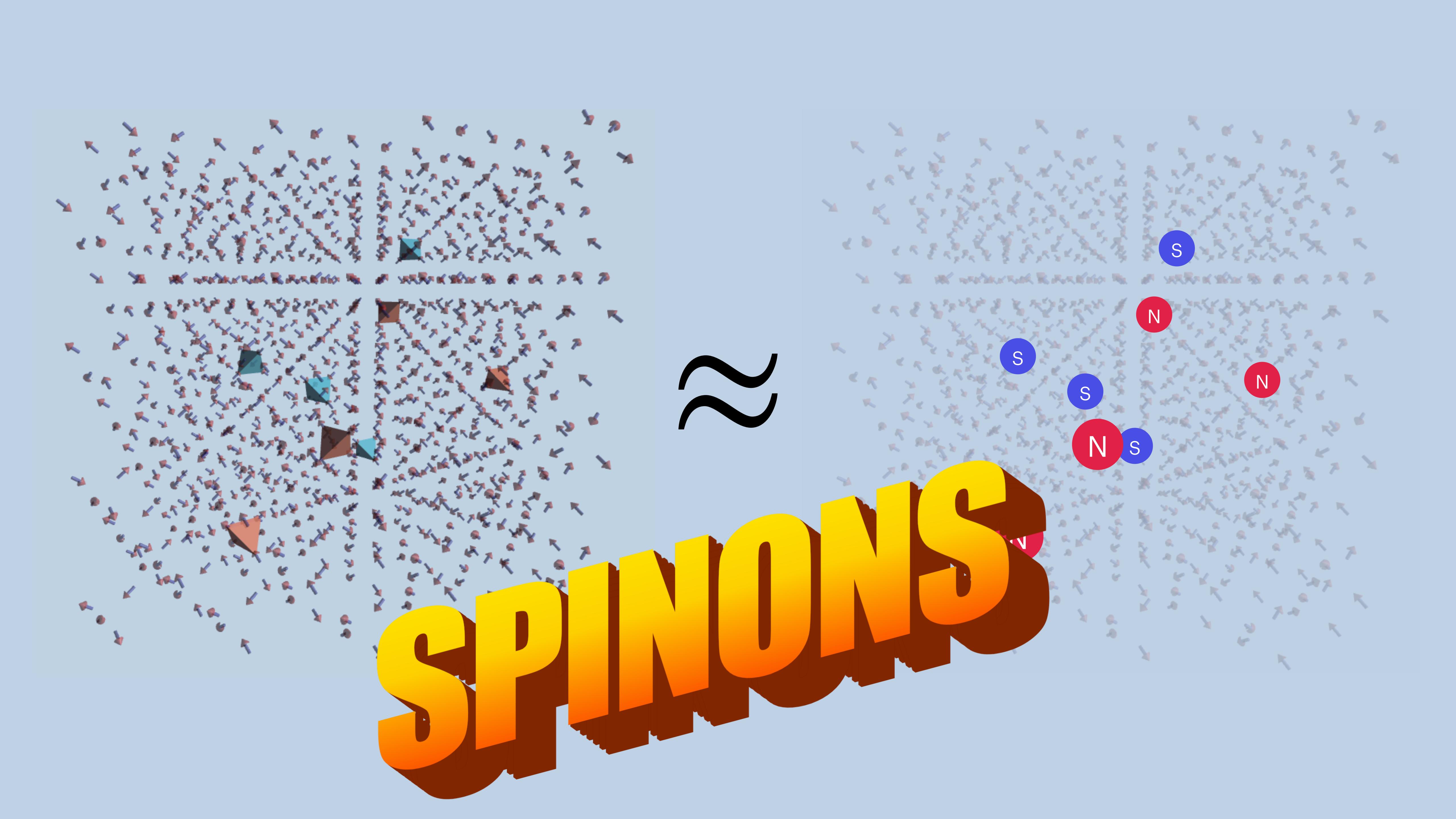


<http://bit.ly/3xLrkIN>



# Quantum Electrodynamics (QED)





# SPINONS

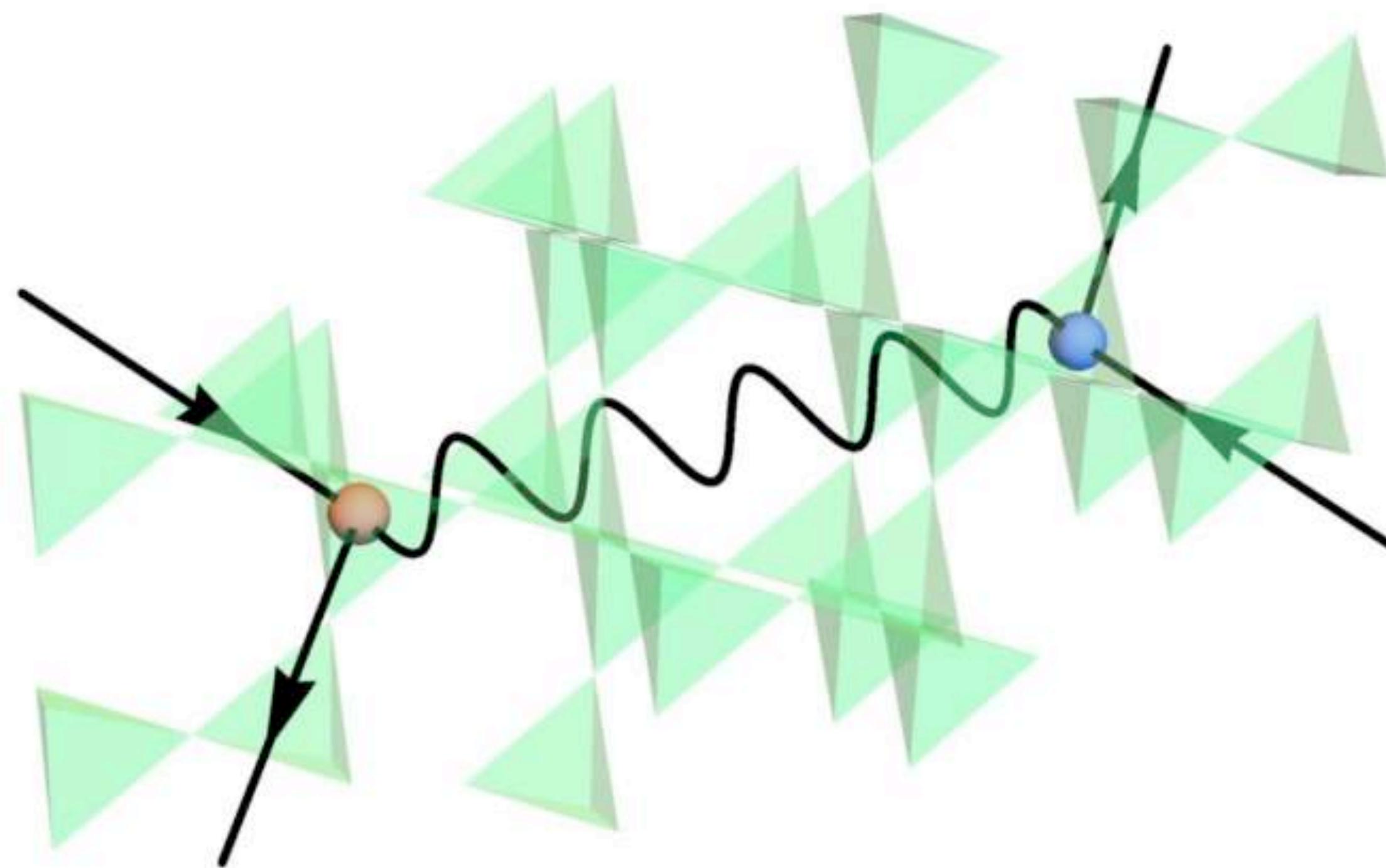
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# Summary: Classical Spin Ice

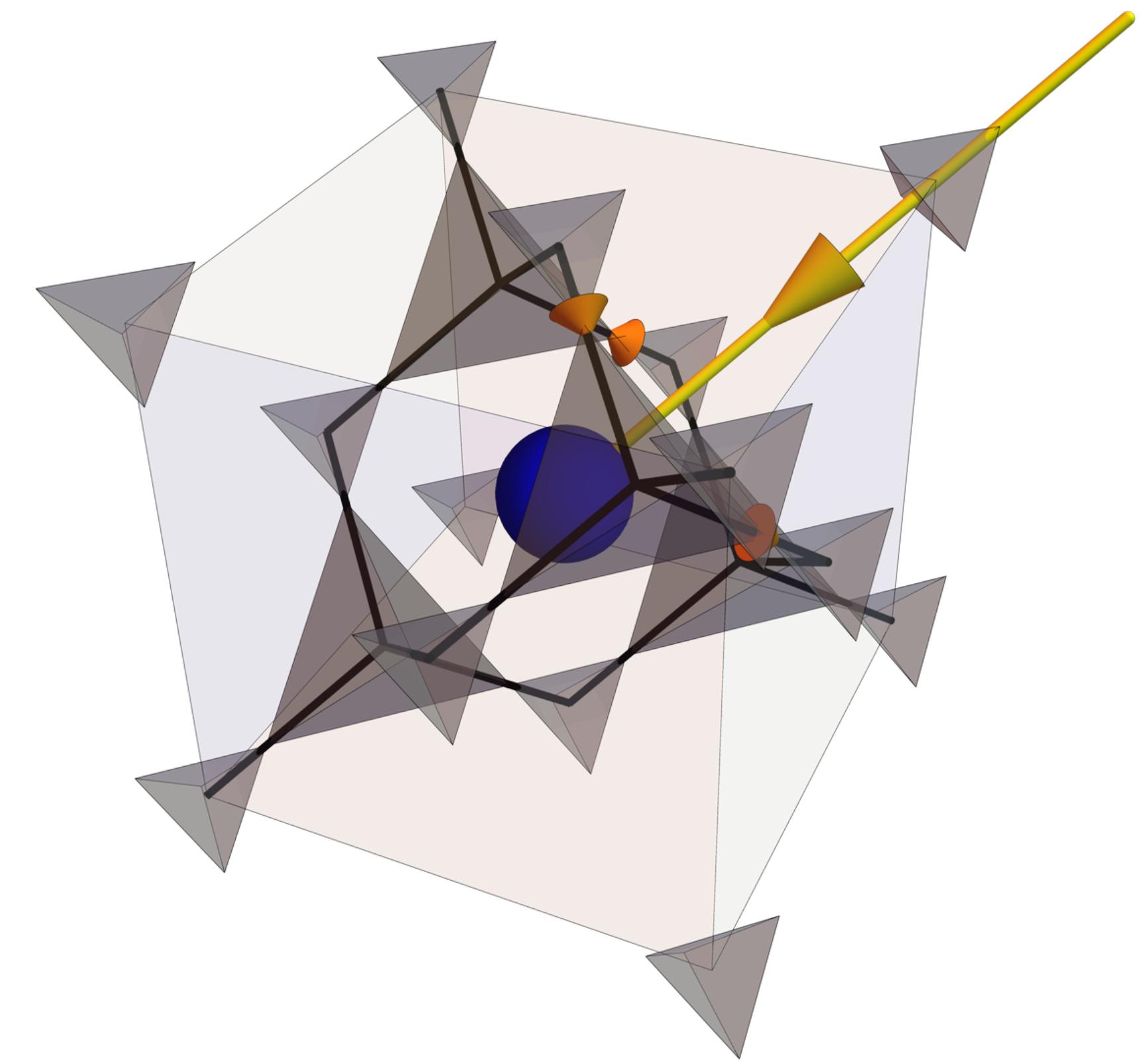
- The base model: spins in a crystal
- Magnetism is frustrated
- 2 in, 2 out constraint à la H<sub>2</sub>O
- Elementary excitations of the system are, for most intents and purposes, magnetic monopoles
- These monopoles move at random in the bulk.



# Quantum Spin Ice

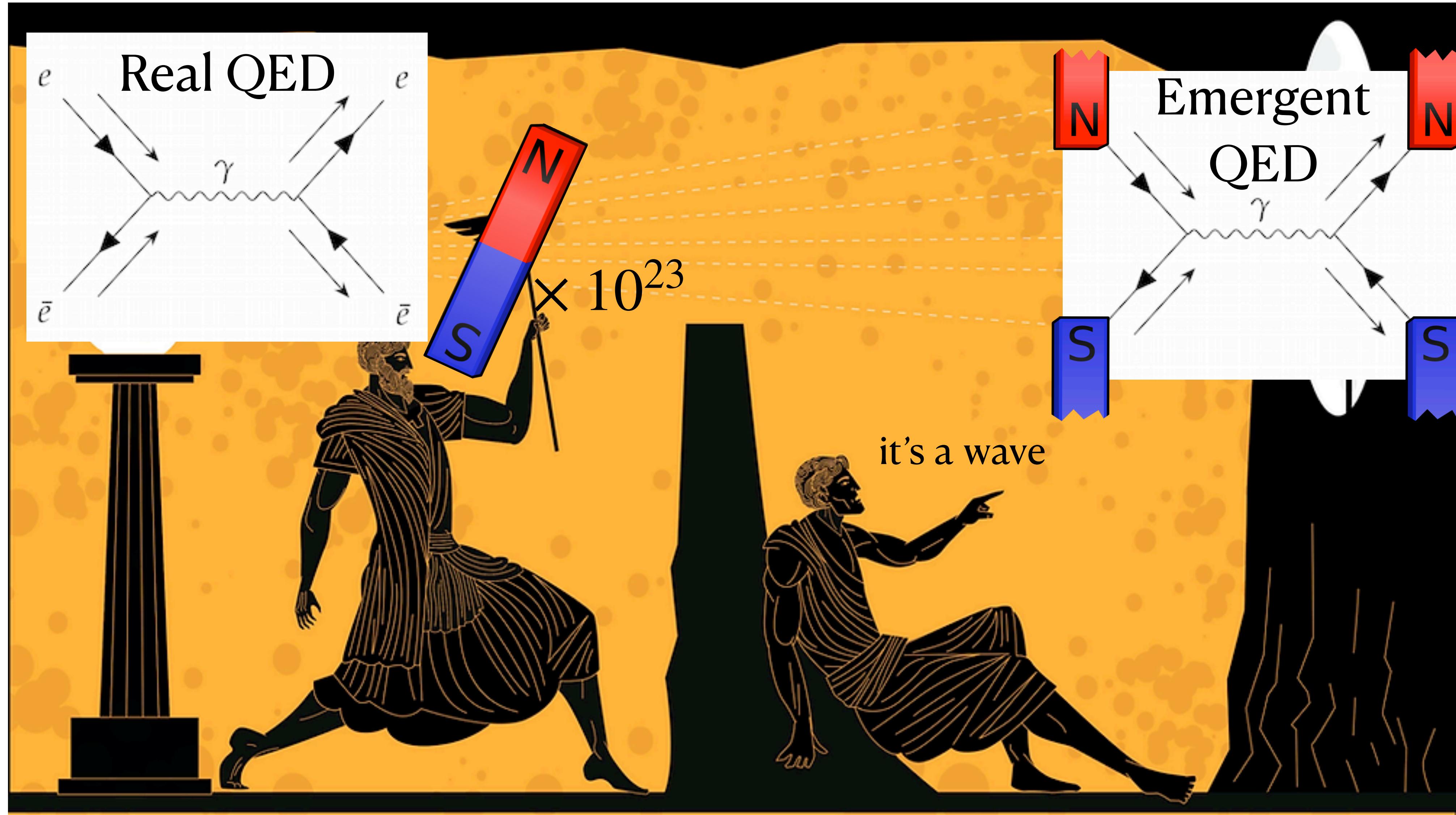


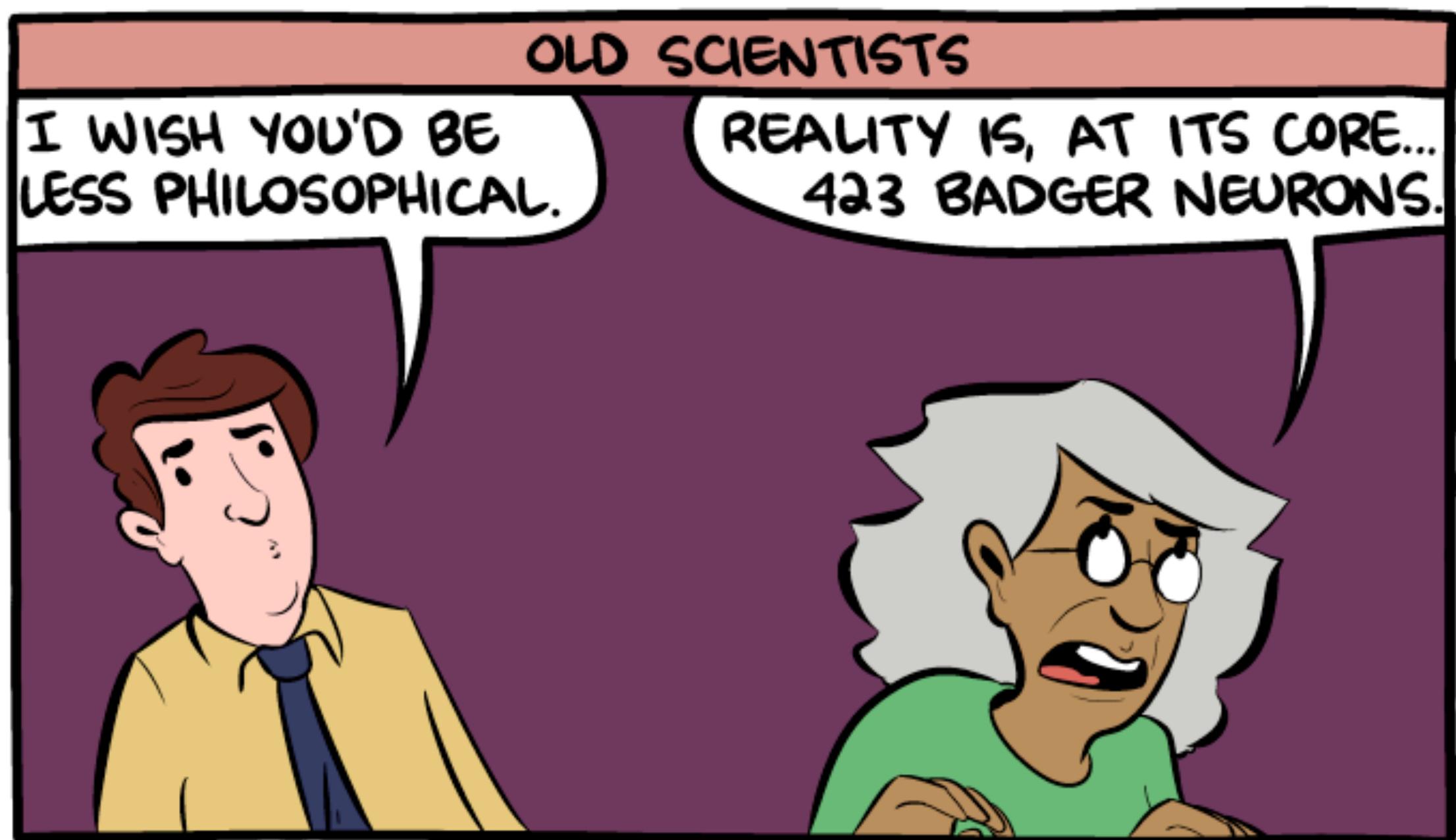
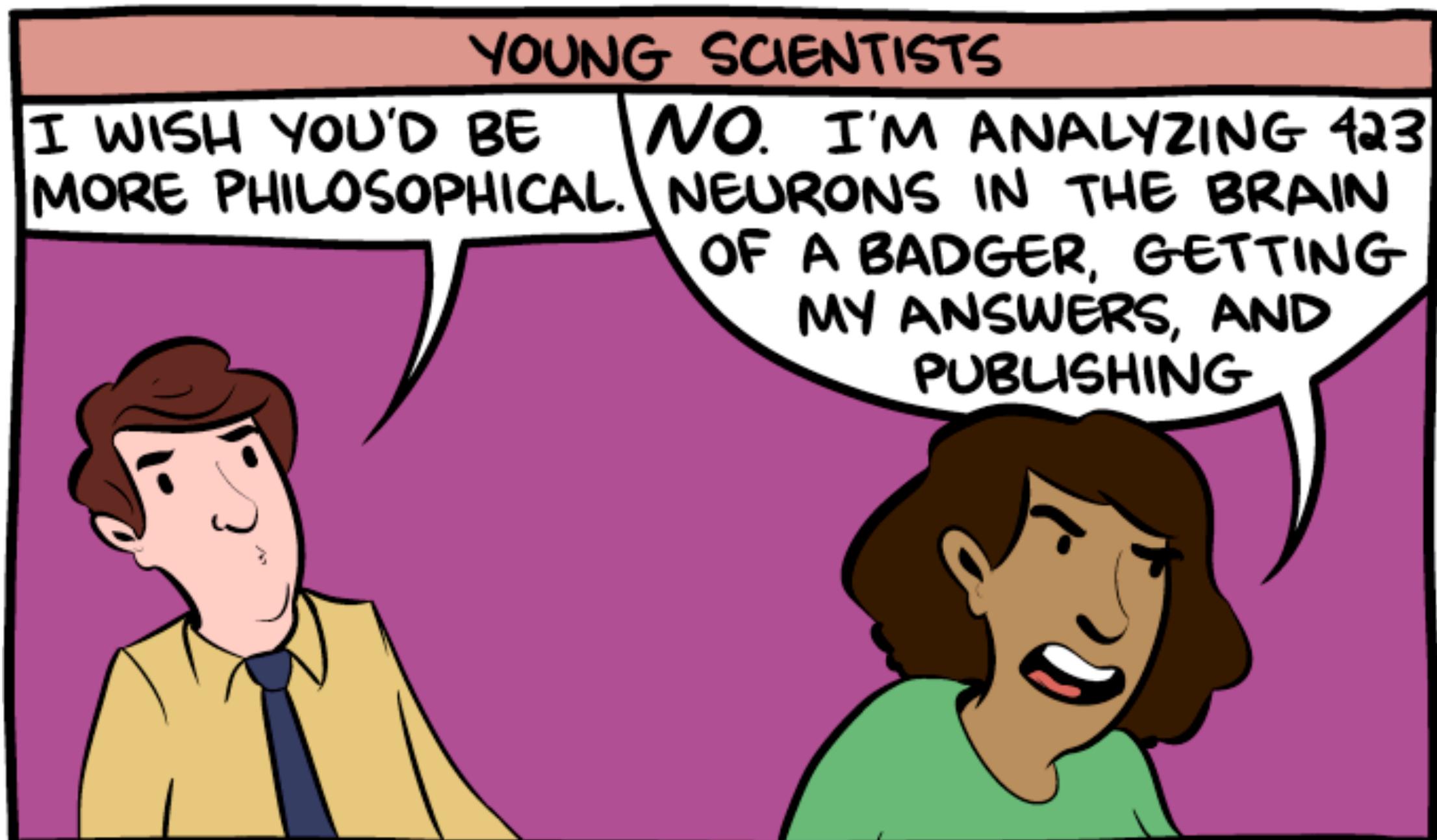
Salvatore D. Pace, Siddhardh C. Morampudi, Roderich Moessner and Chris R. Laumann  
“Emergent fine structure constant of quantum spin ice is large”



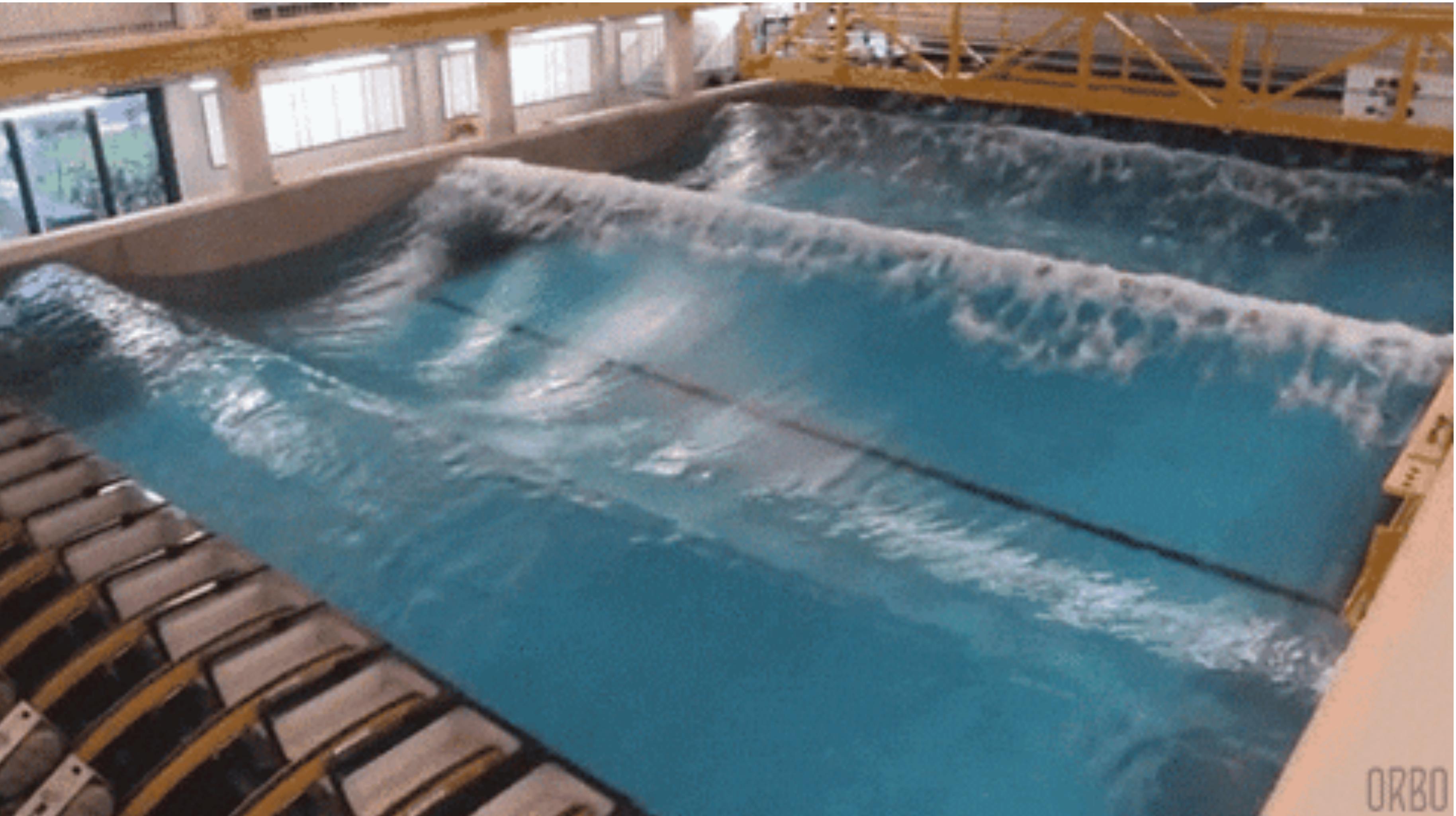
ALS, Claudio Castelnovo  
“Vison crystal in quantum spin ice on the breathing pyrochlore lattice”

# Emergence





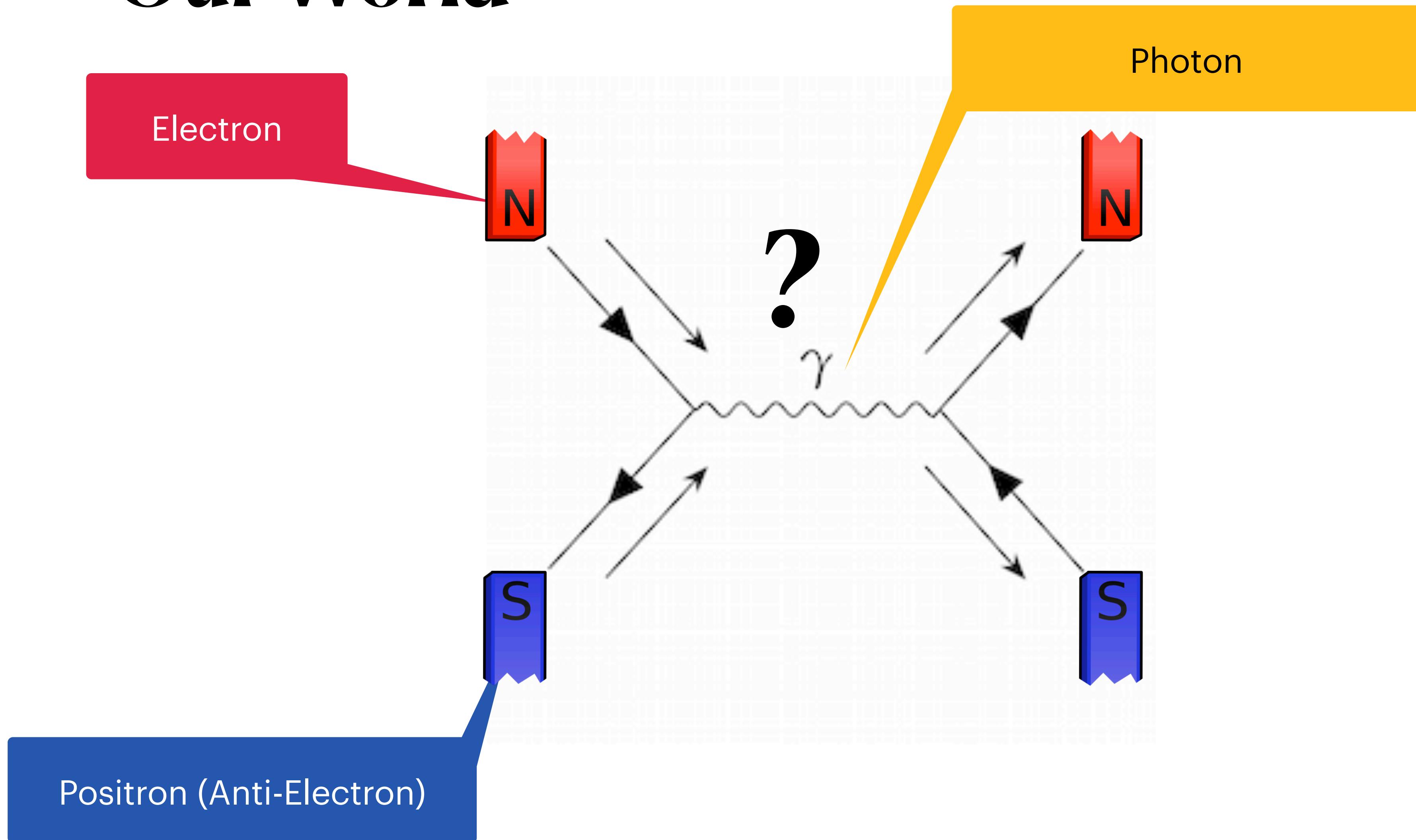
# Emergence



# Phenomenology

	<b>Electrons / Positrons</b>	<b>Spinons / Antispinons</b>
<b>Created and annihilated in pairs</b>	✓	✓
<b>Force between particles</b>	$-\frac{q_1 q_2}{r^2}$ (Electric)	$-\frac{q_1 q_2}{r^2}$ (Magnetic)
<b>Propagation</b>	Ballistic (like a billiard ball)	Diffusive (like a random walk)
<b>Force Carrier</b>	Photons	Entropy

# Our World



# Electricity and Magnetism

