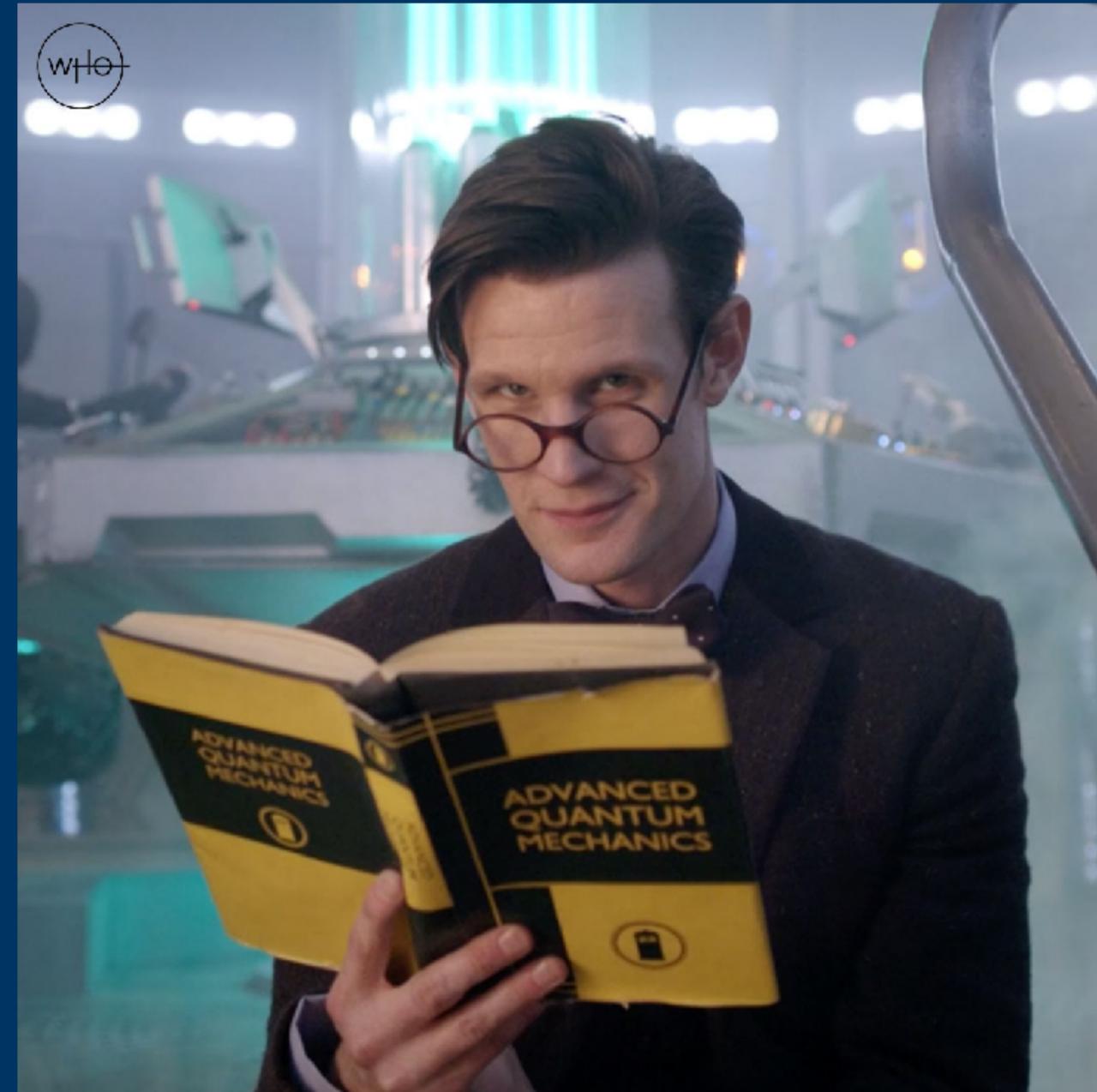


# An Armchair Guide:

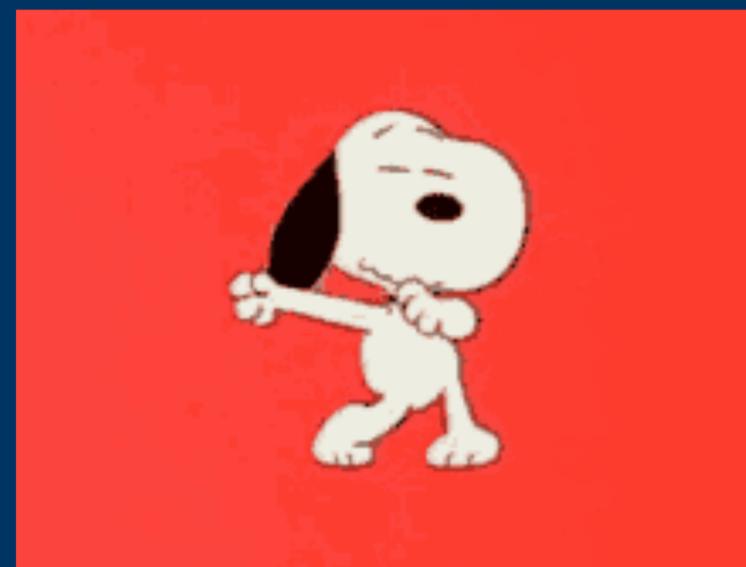
## To Quantum Mechanics



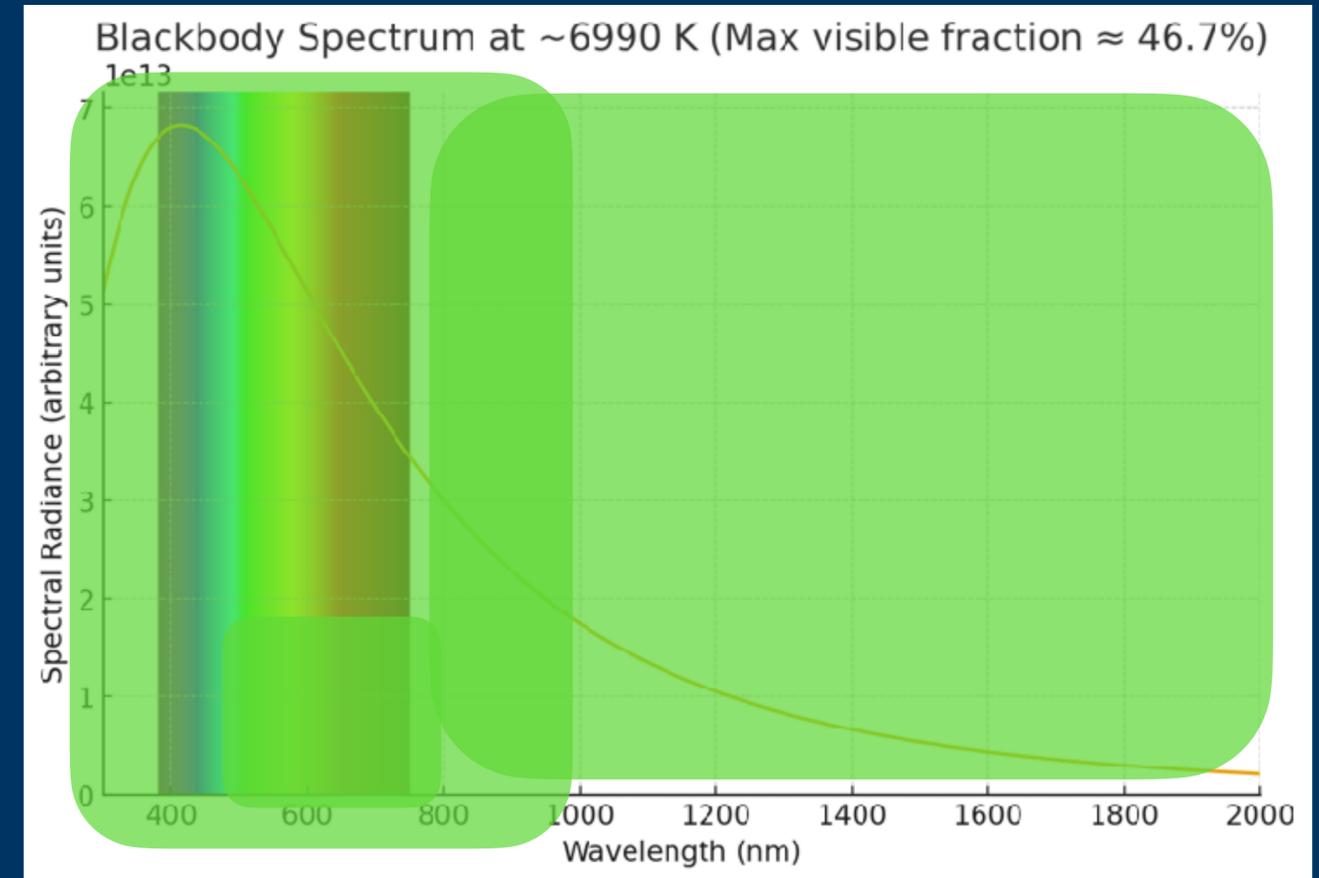
Jonathan Allday

# Session 2:

Come on everyone, let's do the twist....



# Warm (solid) objects...



Most energy in visible region  
Most energy emitted as IR  
Some in long wave visible

Objects glow 'white-hot'

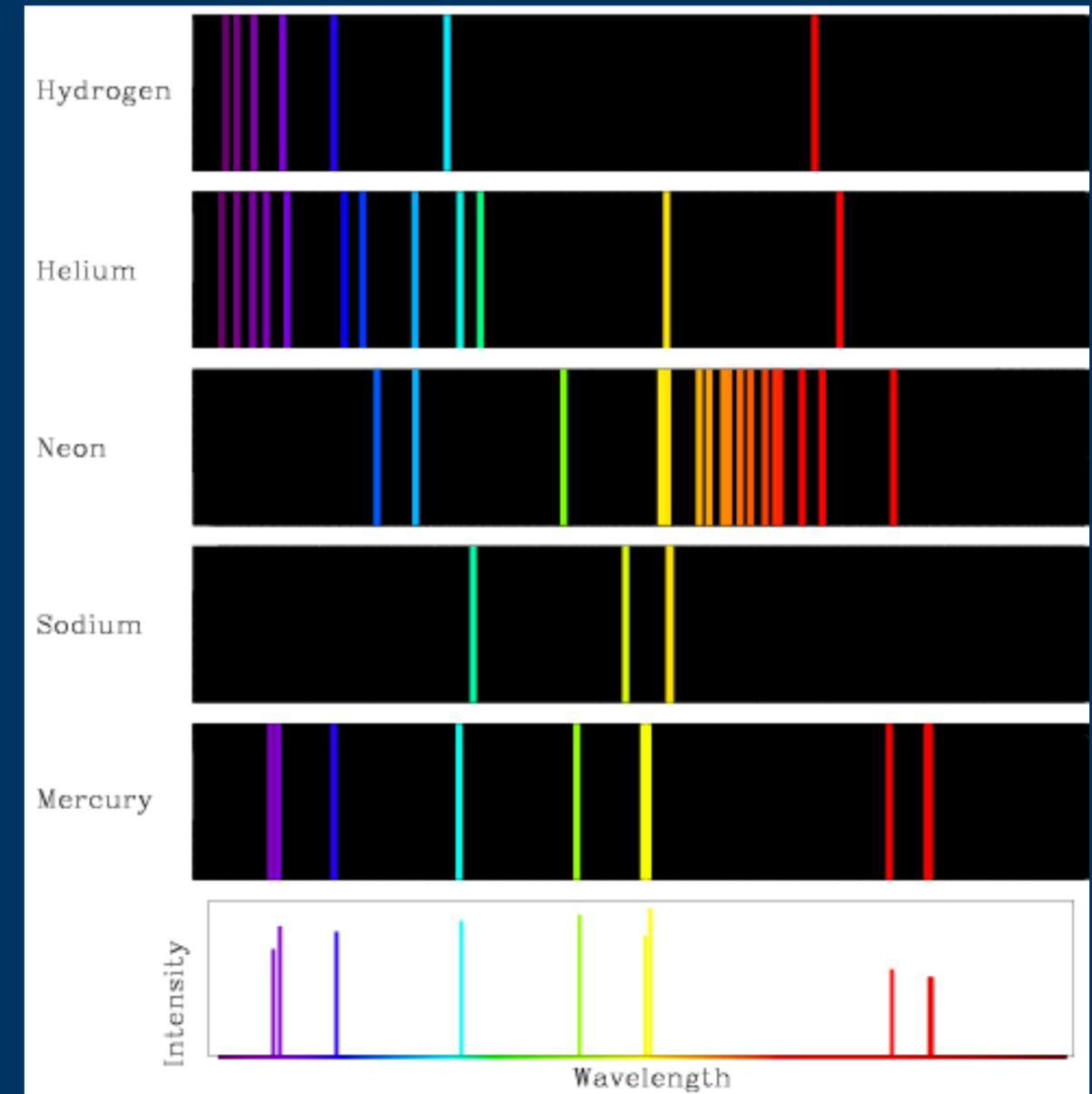
Continuous spectrum that shifts with temperature

# Warm (gaseous) objects...



Atoms behaving **independently**

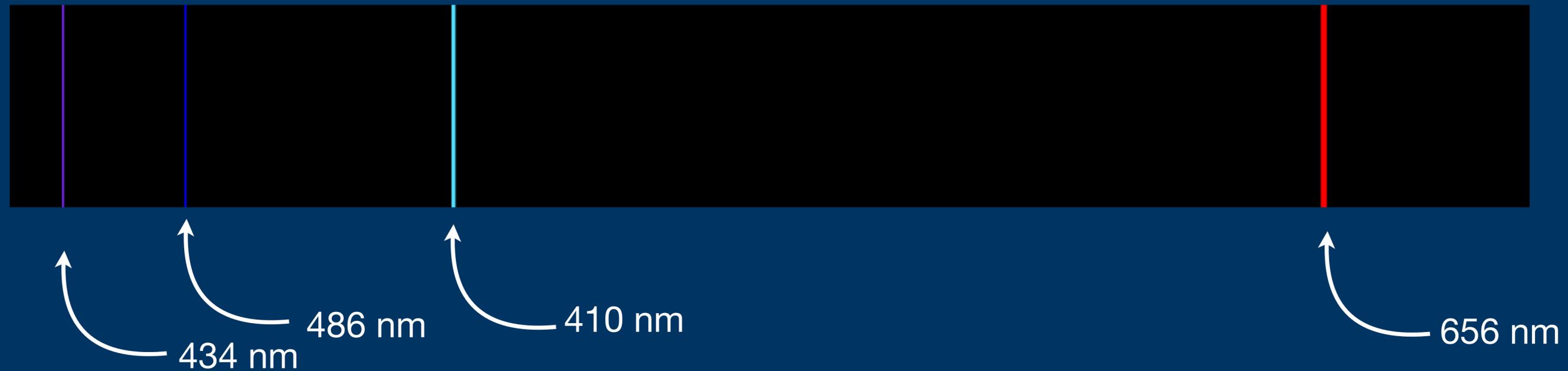
Line spectra **characteristic of the element**



Line spectra

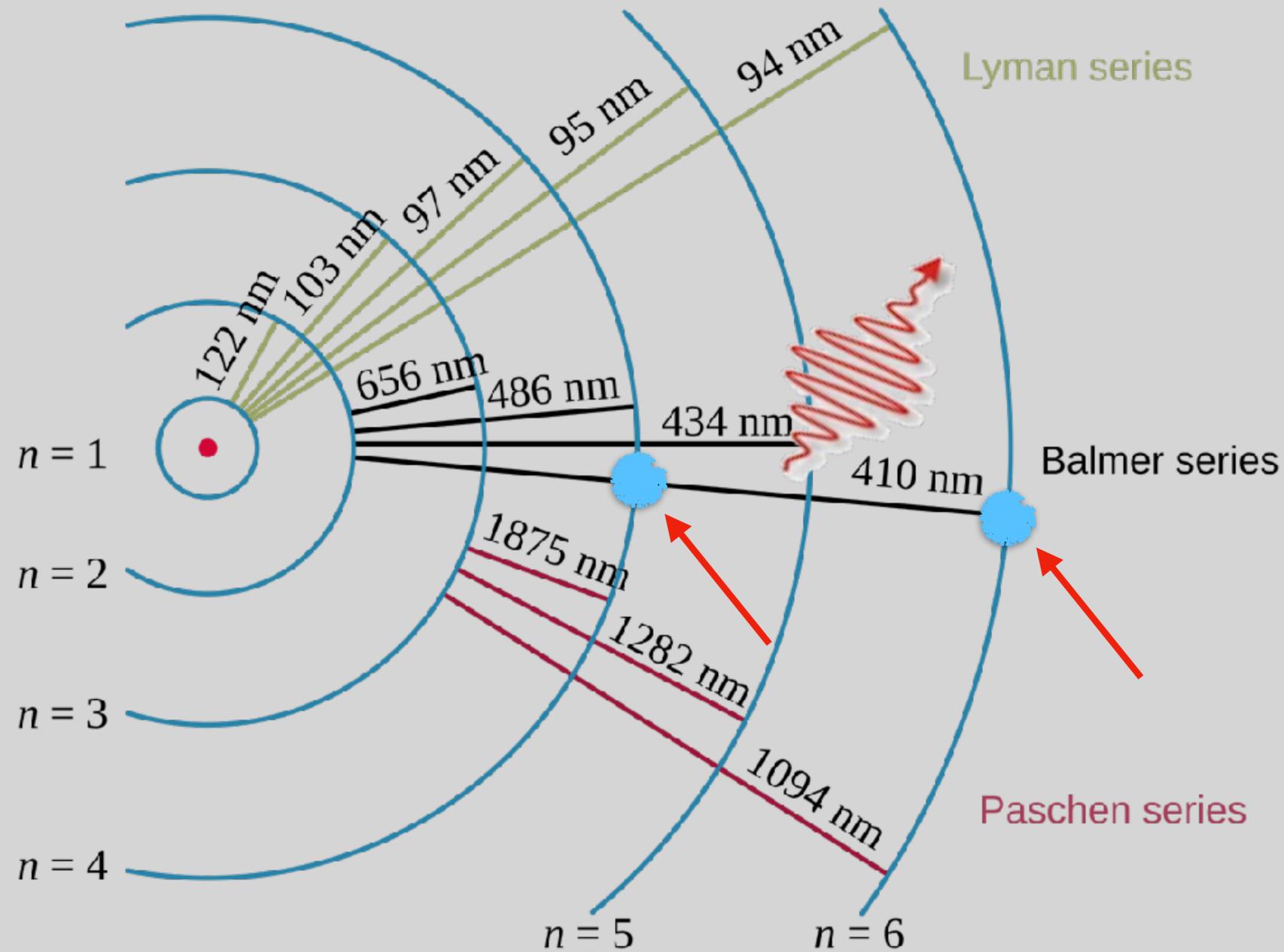
# Visible spectrum of Hydrogen

The **Balmer Series** - visible light

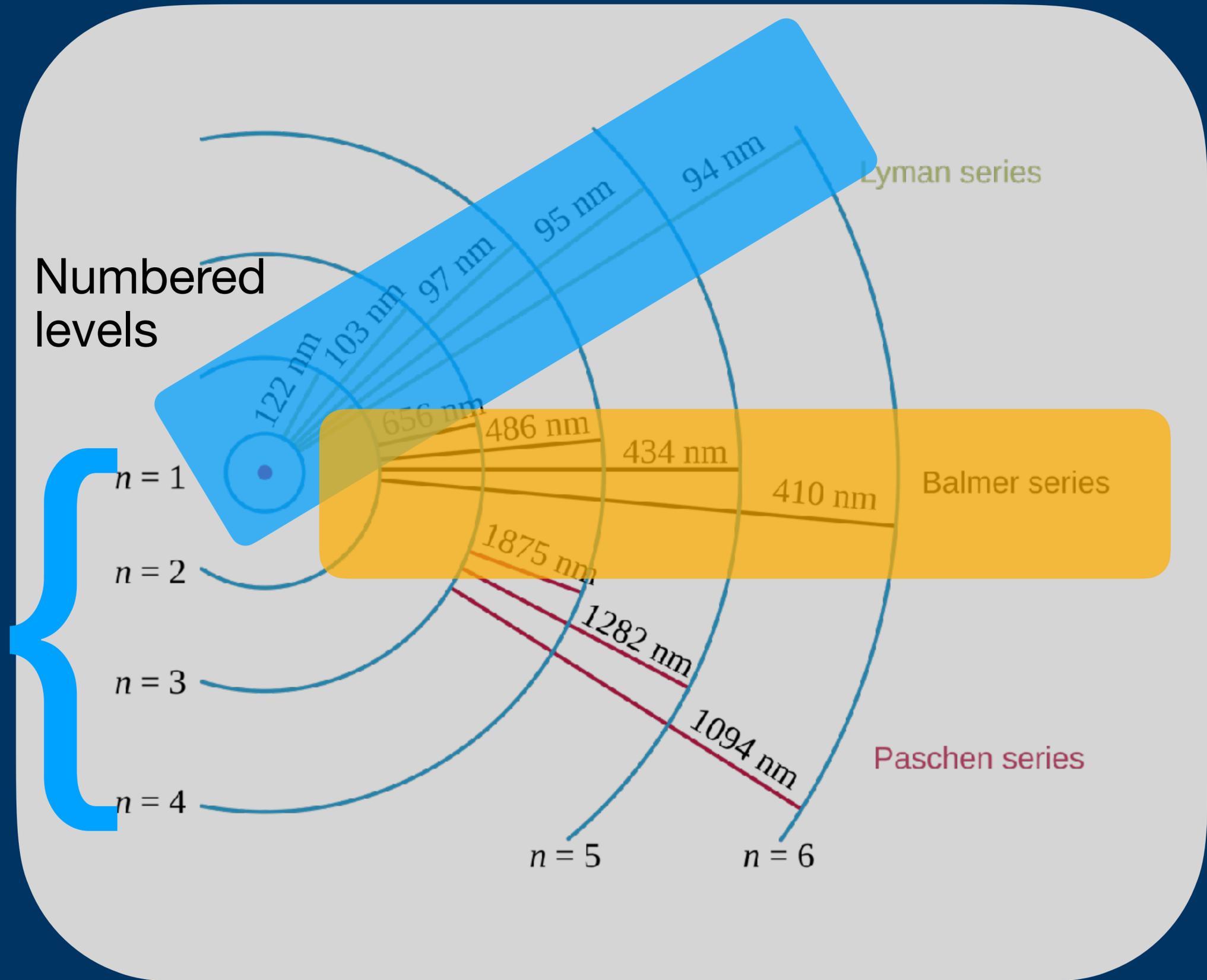


## Electron in energy level

- ‘Falls’ to a lower level
- Emits a photon
- Energy of photon = difference in energy in levels



There are no paths in QM!

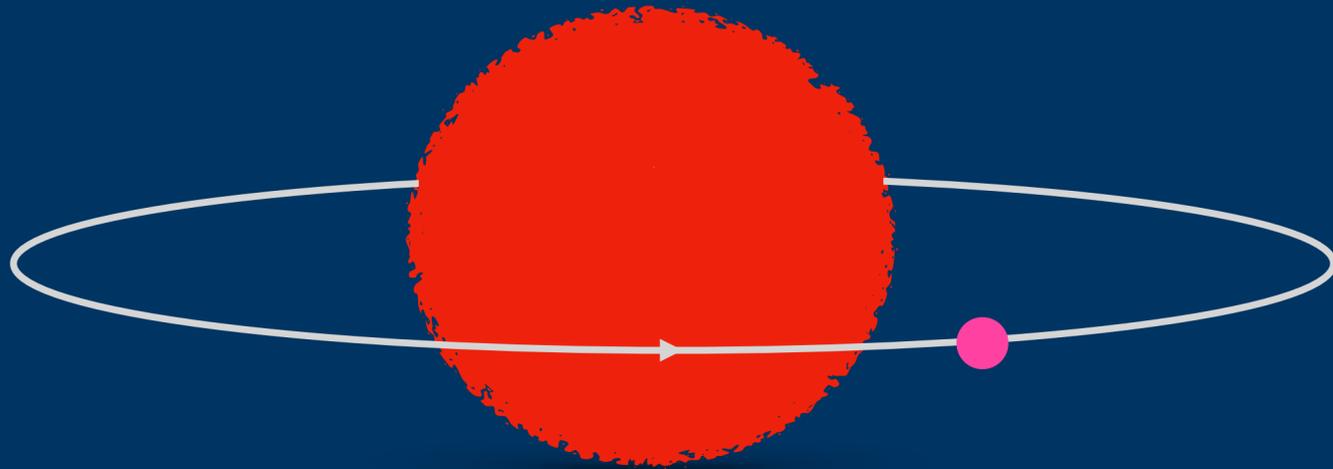


Electron in energy level

- Every drop into level 1
- Lyman Series

Electron in energy level

- Every drop into level 2
- Balmer Series
- These are visible light

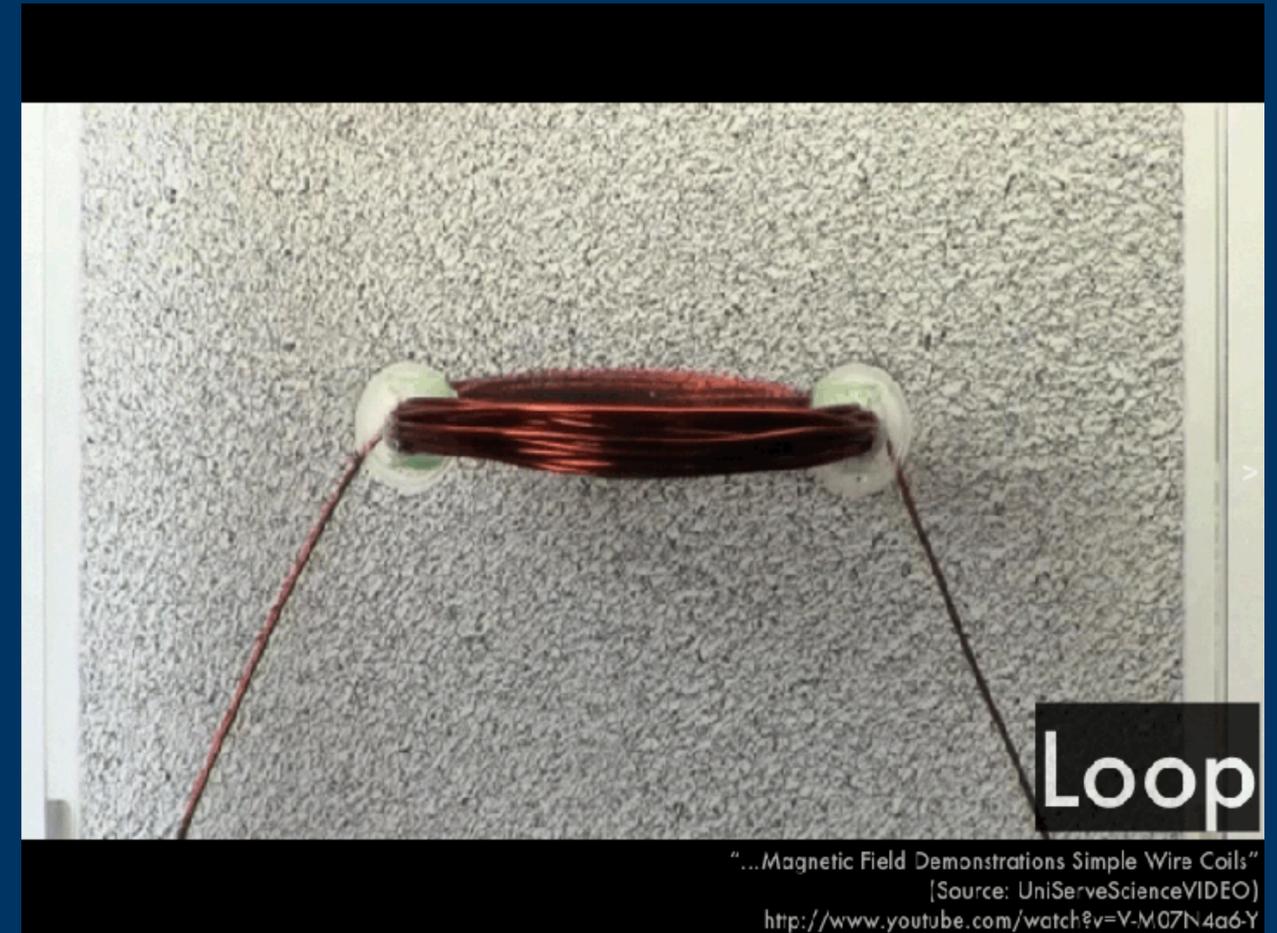


Electron in 'orbit' around nucleus

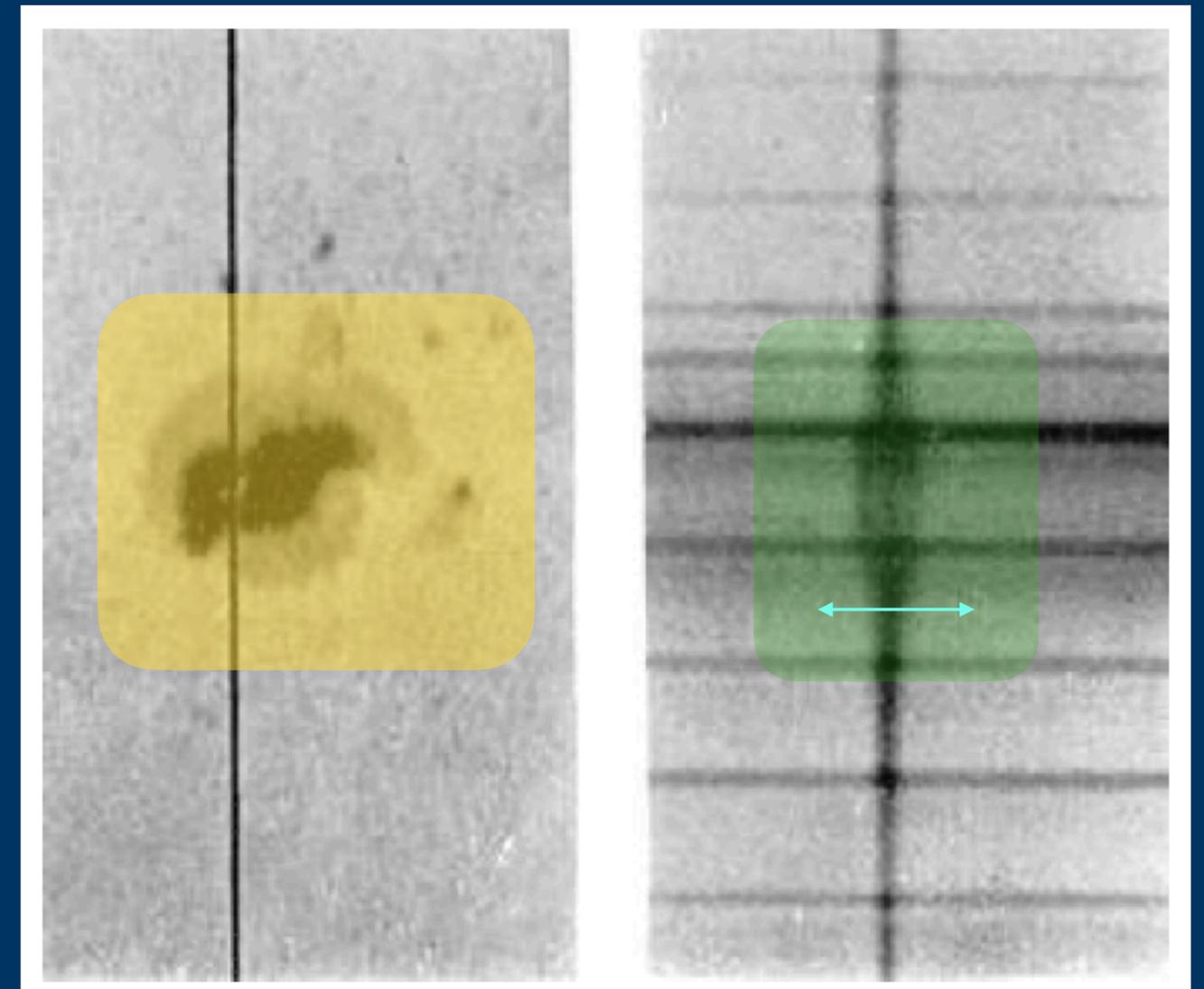
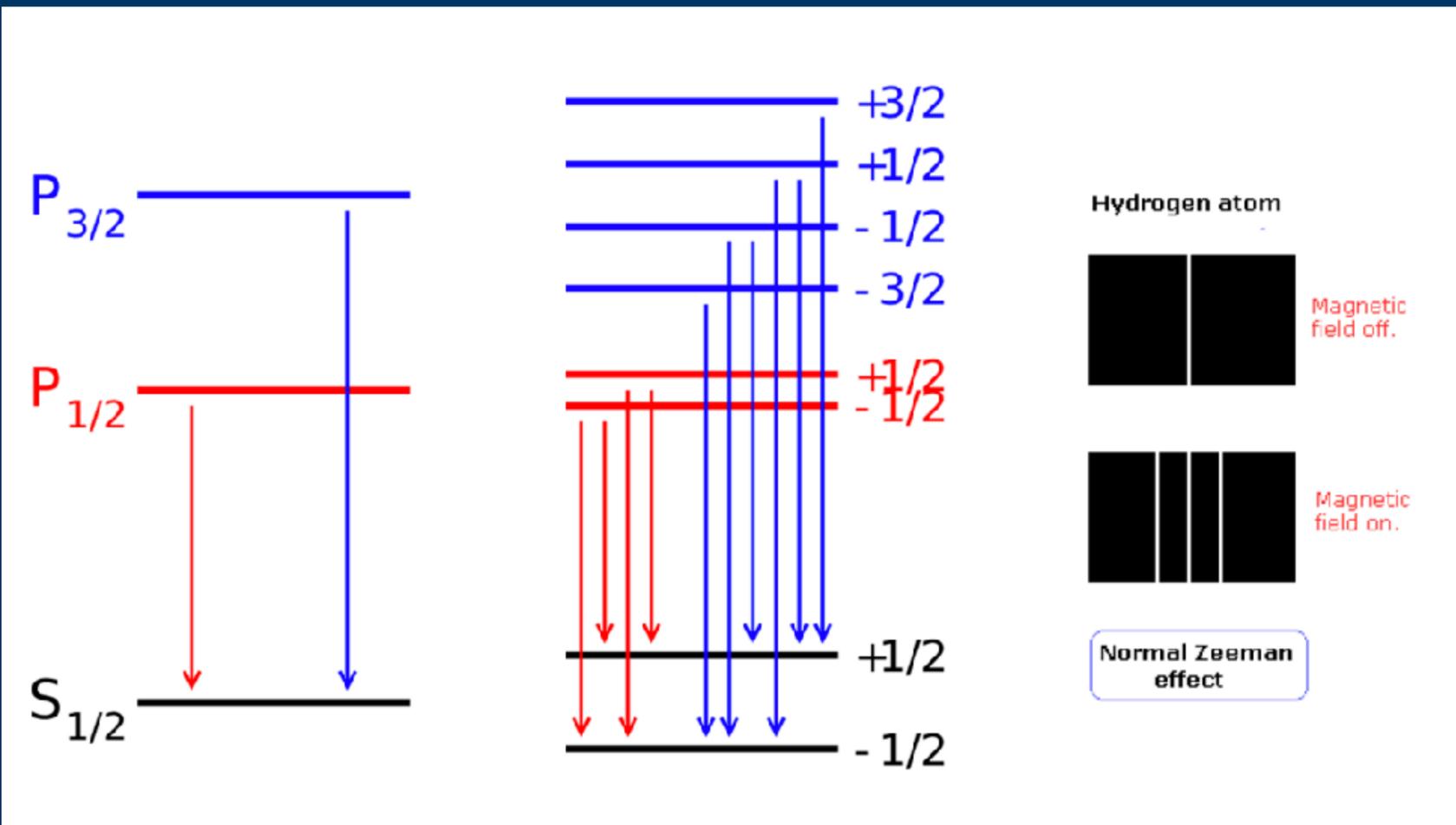
Like a current in a wire loop

Creates a magnetic field

In an external field - splits the energy levels

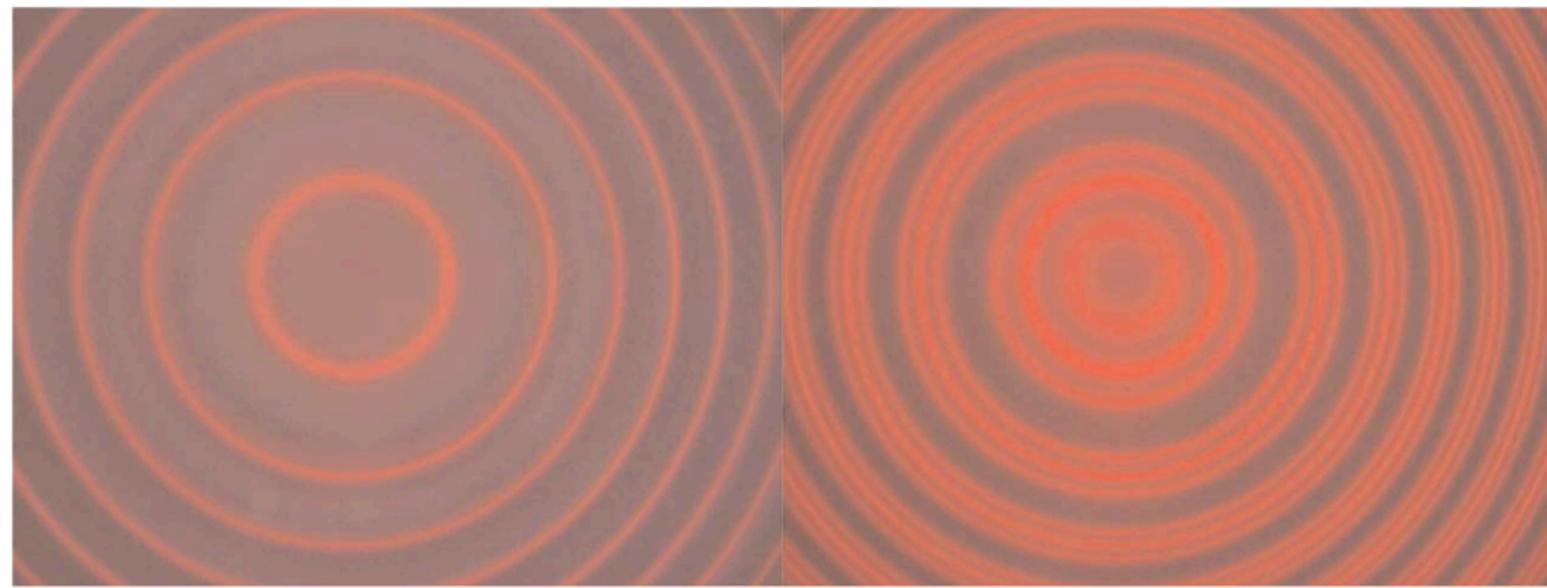


There are no paths in QM!



Sunspot

Splits the spectral lines



Normal

Fig.10: Normal Zeeman effect: Interference pattern without polarization filter for no coil current and for 5 A coil current. On the left there is one ring per order of interference, on the right there are three rings per order of interference

Better resolution reveals even further splitting

Not explained by the 'orbital' magnetic field...

Does the electron have its own intrinsic field?

Anomalous Phenomenon...

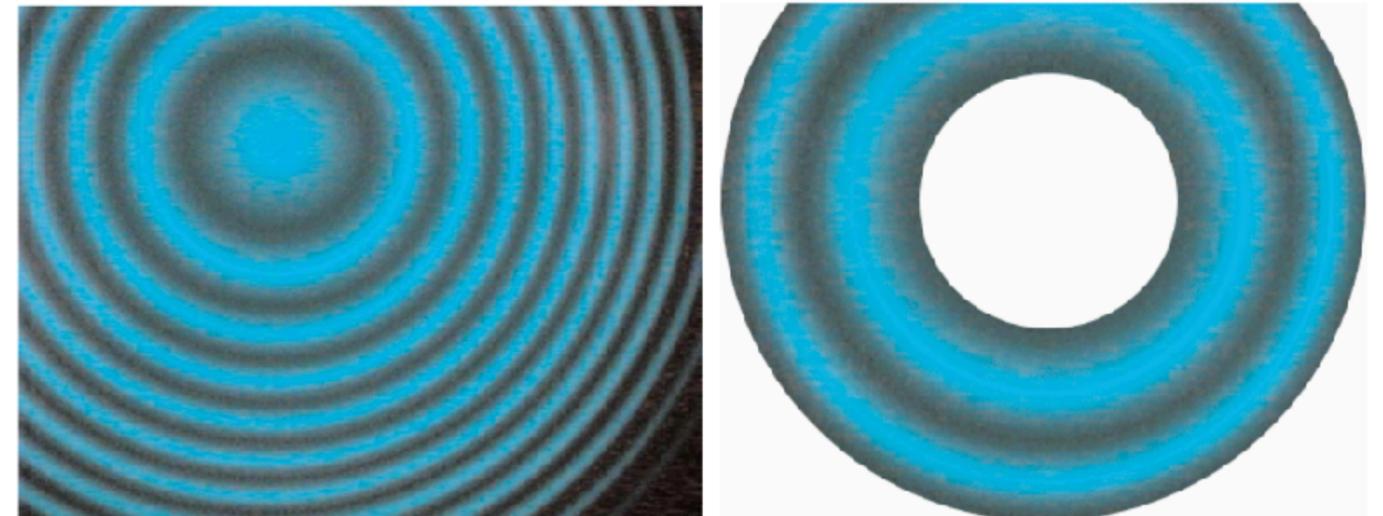


Fig. 12: Anomalous Zeeman effect: Interference pattern with horizontal polarization filter and magnified cut-out of the first complete two orders

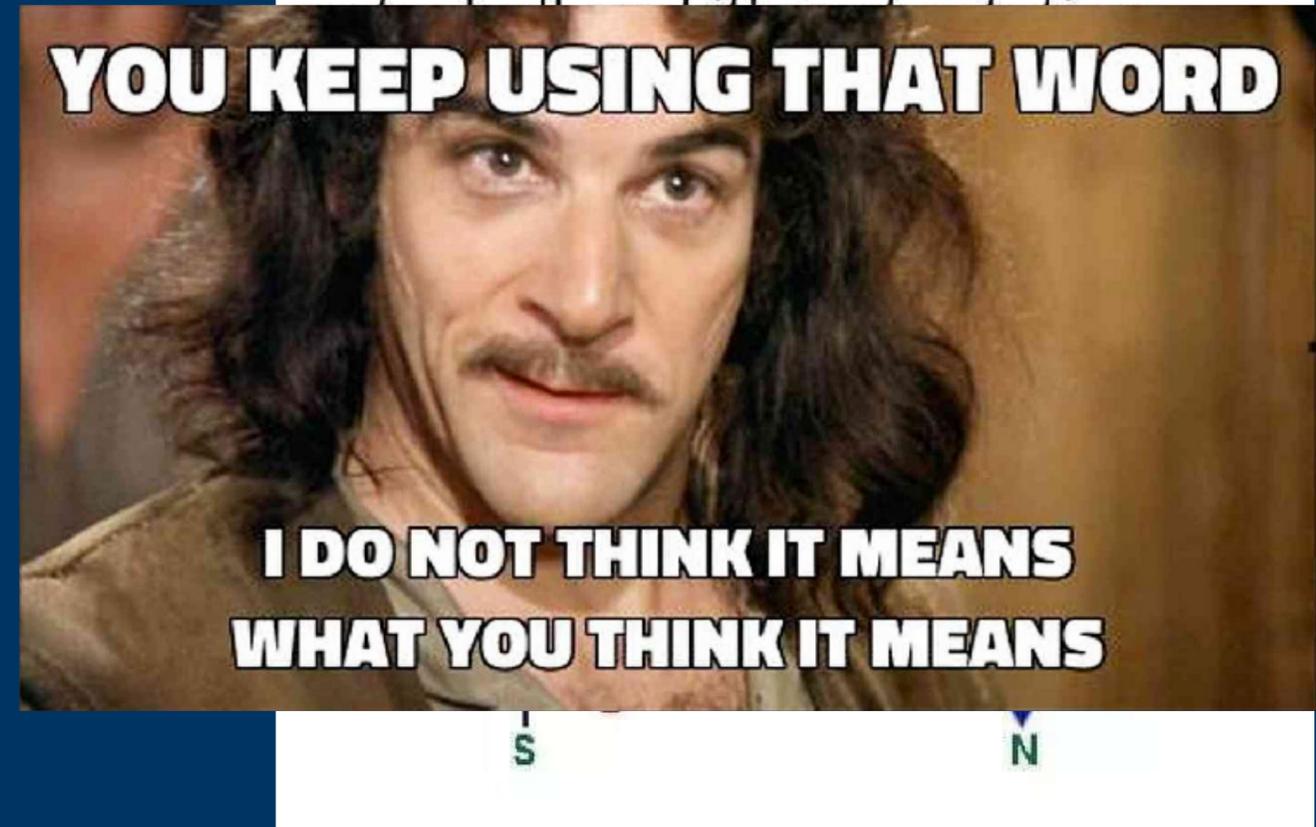
Could not resist...



# Spin

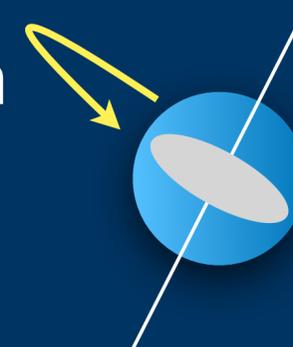
- Quantum mechanical property
- Named as if 'spin' as if it were like a top
  - Causes significant difficulties thinking that way
  - E.g. electrons would 'spin' faster than light...

Electron spin explained: imagine a ball that's rotating, except it's



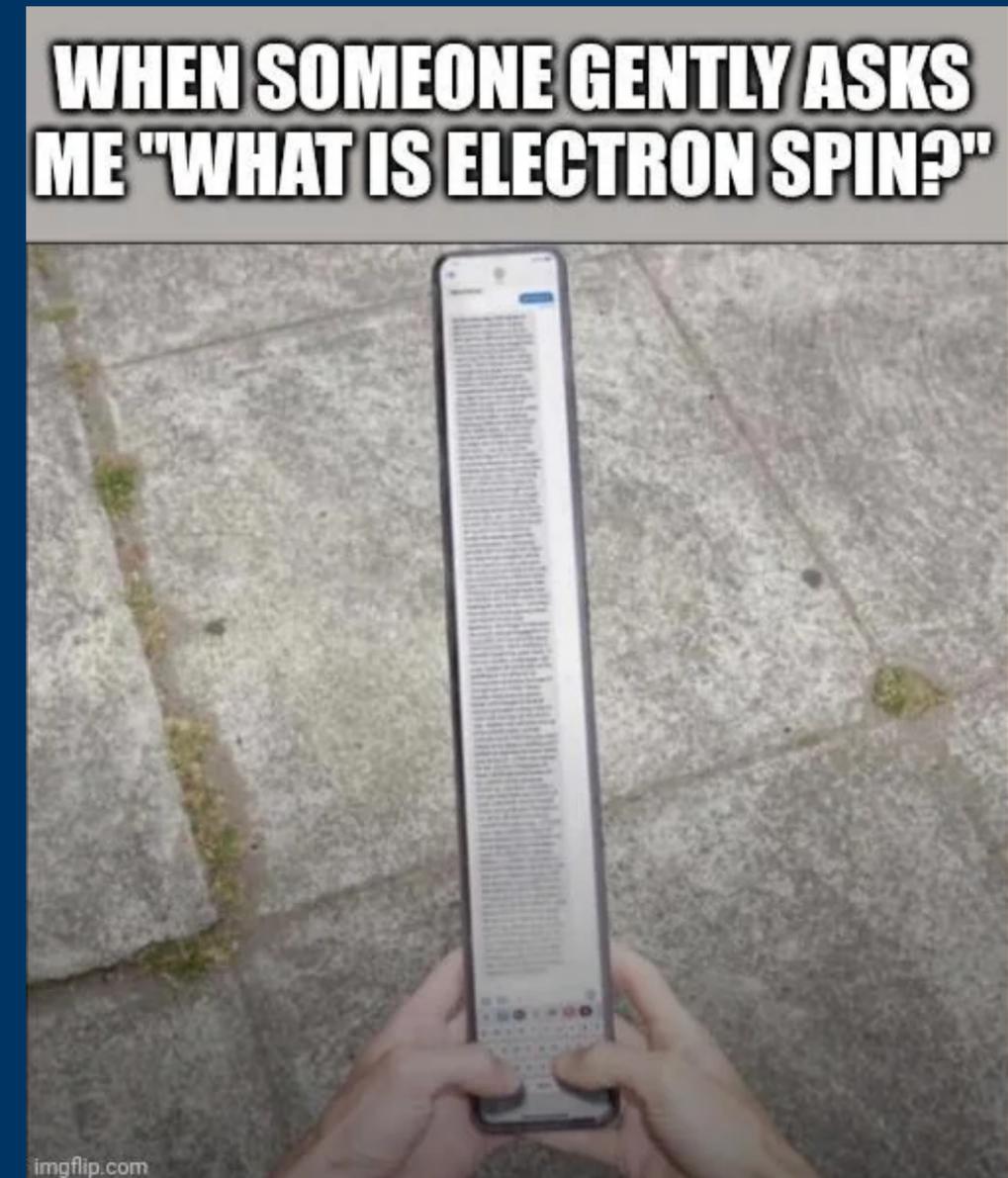
Spin axis - direction of spin

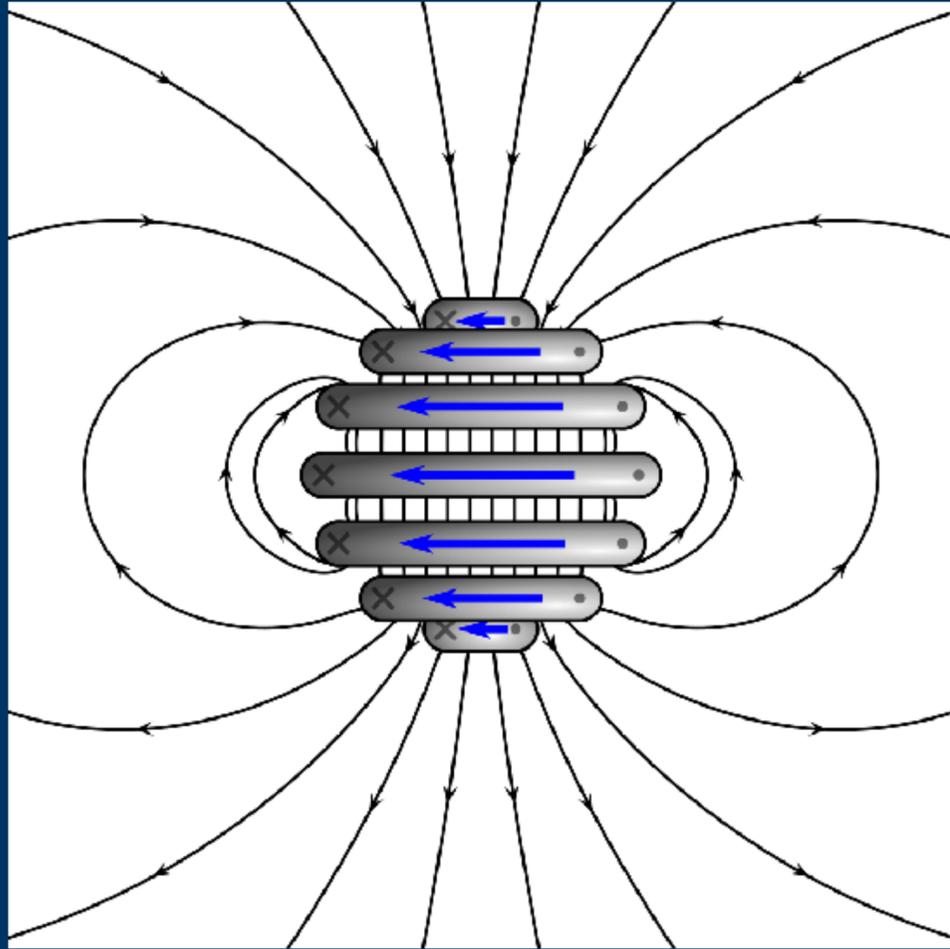
Amount of spin



# Spin

- ‘Amount’ of spin:
    - Fixed
    - Characteristic of the particle
      - Electrons spin- $\frac{1}{2}$ ; photons spin-1
  - ‘Direction’ of spin
    - Spin component
    - Not fixed - but limited
- Spin axis - direction of spin





Classically, a **charged sphere** is like lots of current loops  
So, a **spinning electron** would have a **small magnetic field**

Classically:

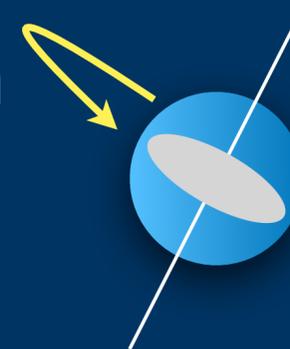
Could rotate at **any rate**:

**Any strength** of field

Spin **axis** in **any direction**...

Spin axis - direction of spin

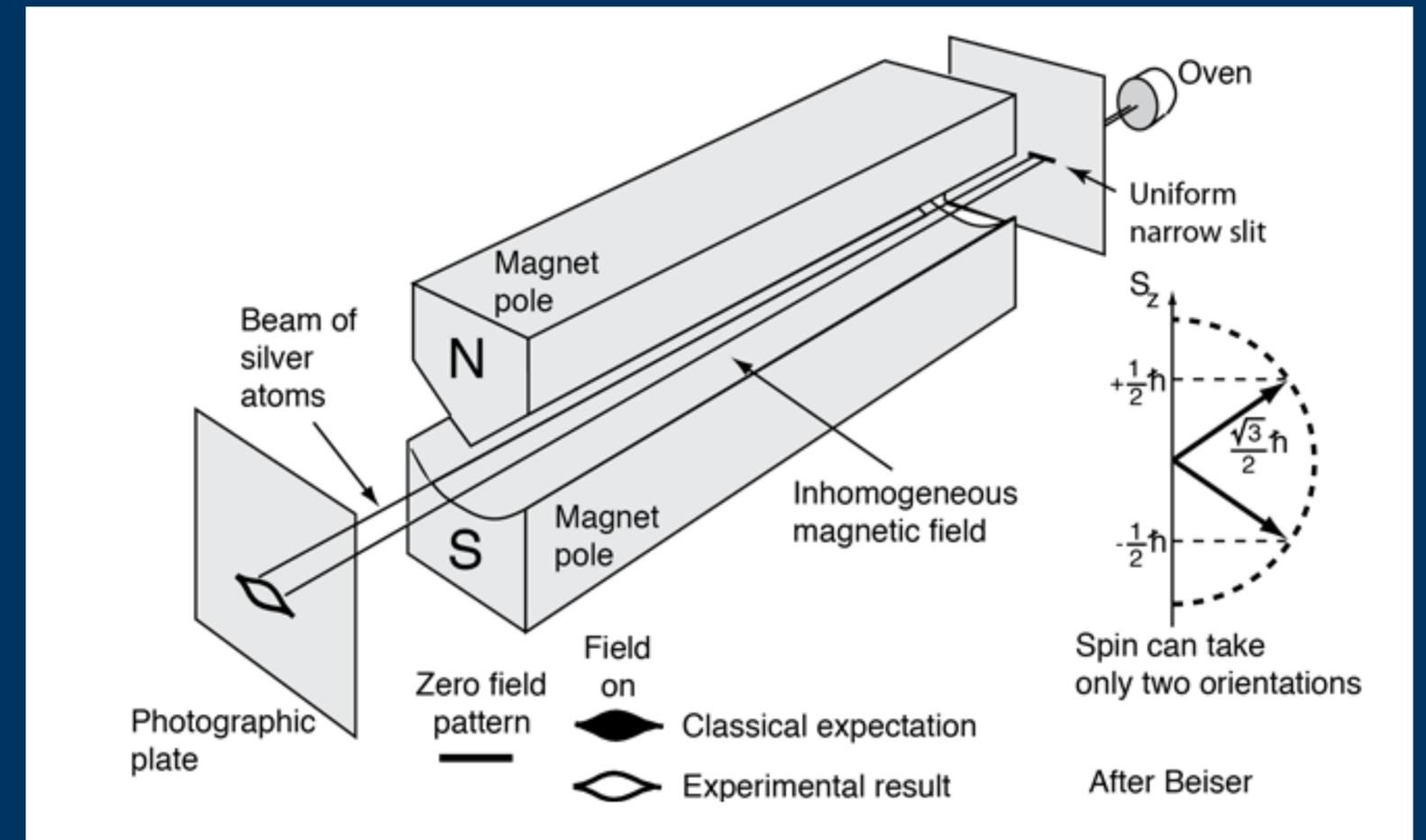
Amount of spin



But electrons are not classical...

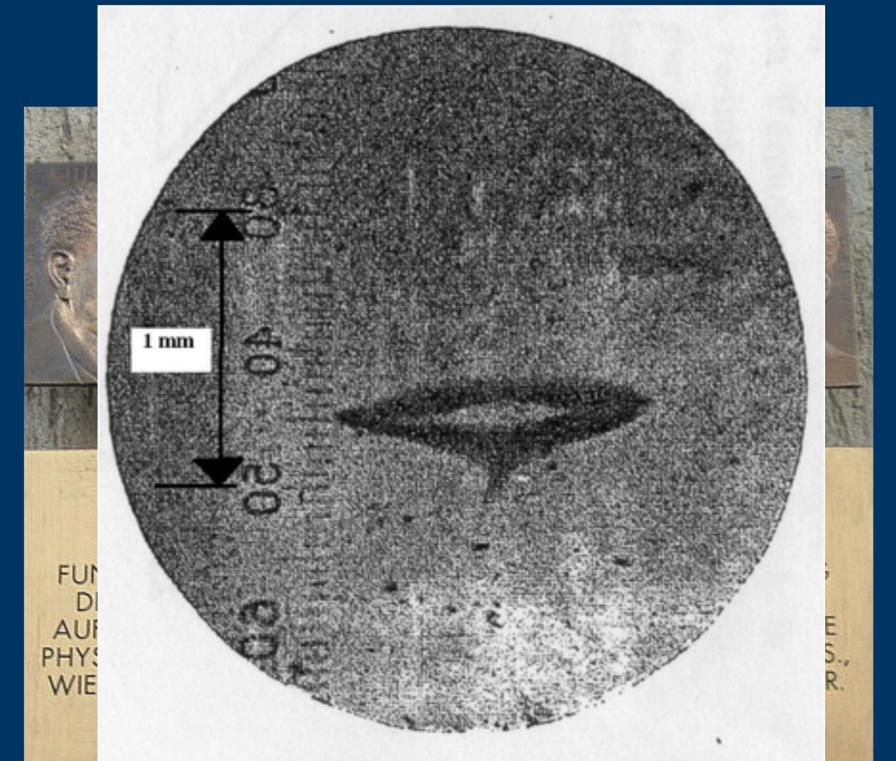
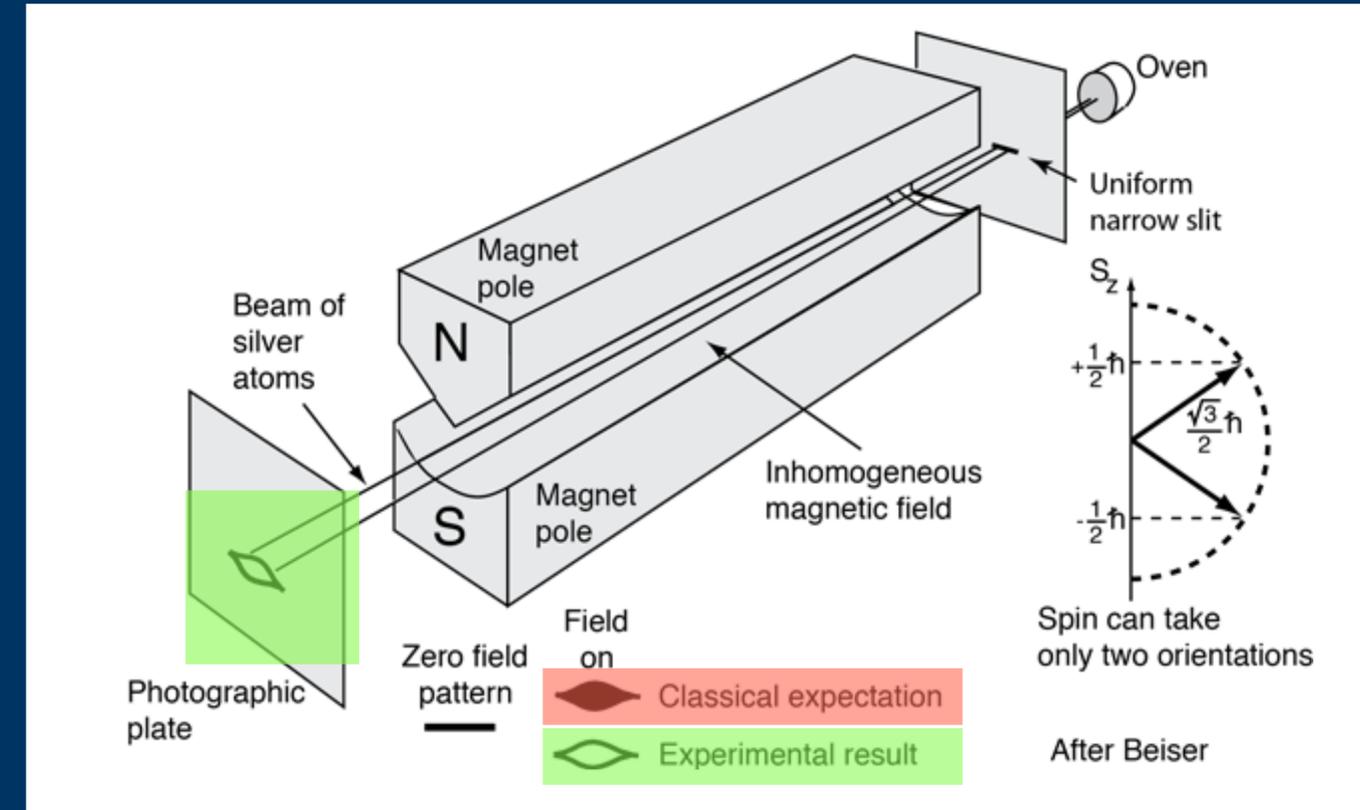
Can be shown to have a magnetic field

Get deflected by a magnet...



# Experiment

- Stern Gerlach experiment
  - Experiment done with a beam of **silver atoms**
  - Effect **actually** due to **electrons** in the atom
  - Magnet **deflects** the **electrons**
  - Classically **expect** a continuous ‘smear’
    - As the **spin axis** can have any angle
      - The beam must have a **mixture of angles...**
  - **Instead**, **get** a distinctive **split**



Gerlach, W.; Stern, O. (1922). "Der experimentelle Nachweis der Richtungsquantelung im Magnetfeld". Zeitschrift für Physik. 9 (1): 349–352

# Interpretation

- Electron spin component (direction) has:

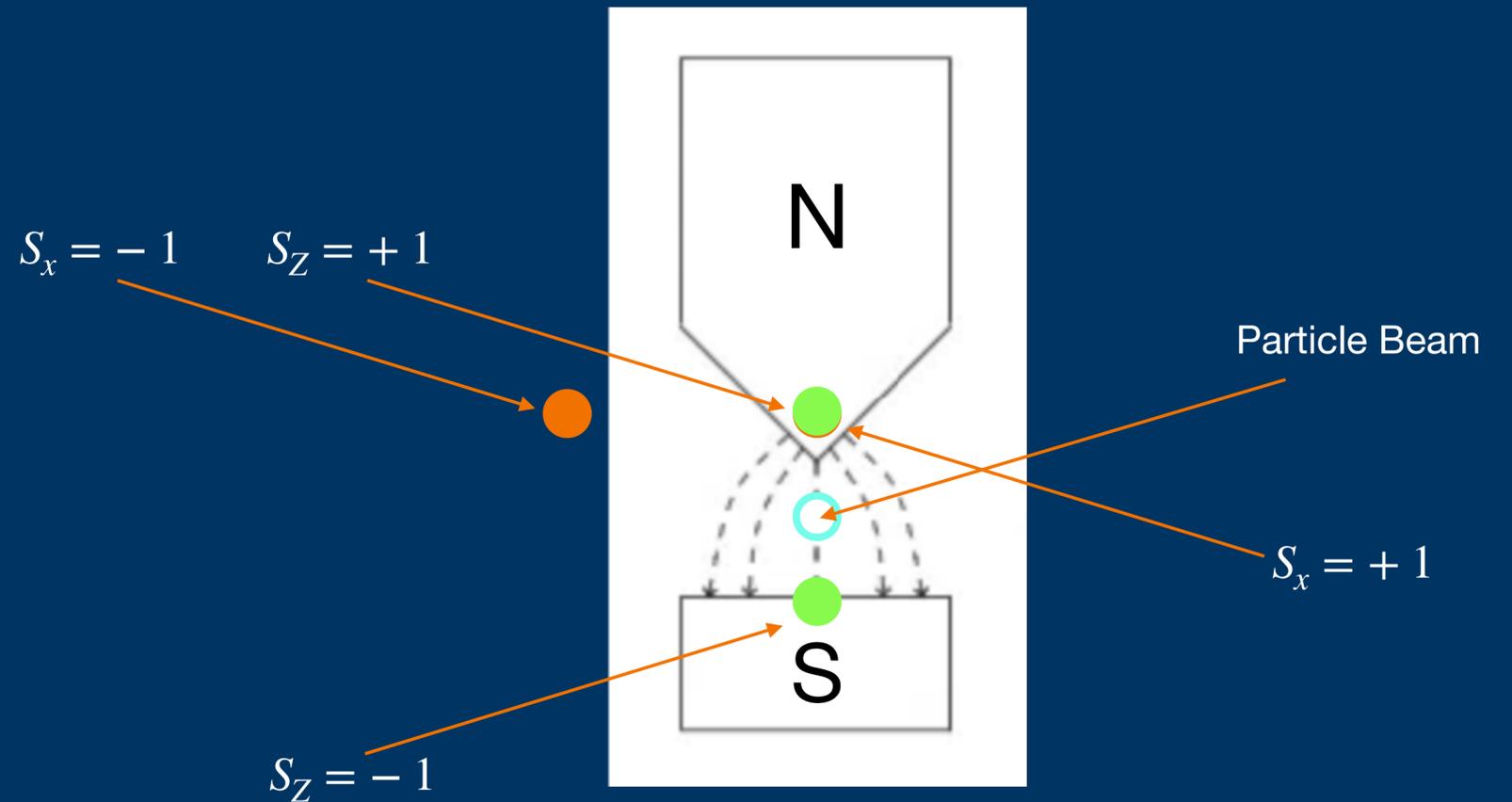
- **Two** distinct values
- **Randomly** manifest
- **Relative** to the **direction** of the **external field**

- **Vertical** field

- Spin **UP** = +1
- Spin **DOWN** = -1

- **Horizontal** field

- Spin **RIGHT** = +1
- Spin **LEFT** = -1



- +1 is always towards **North**

**NB** Magnetic field directions

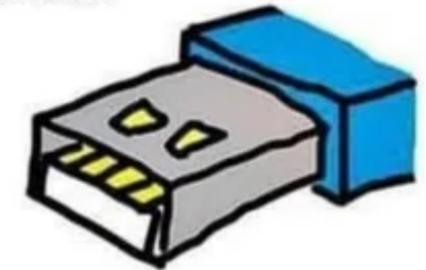
- -1 is always towards **South**

**NBB** There are equivalent ways of doing things for Photons

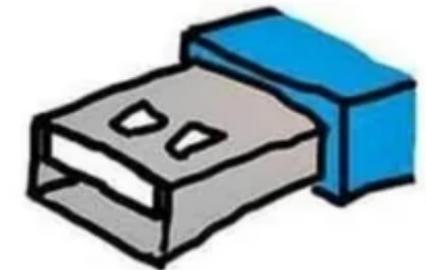
# USB sticks are quantum...

It is a well known fact that you must spin a USB three times before it will fit. From this, we can gather that a USB has three states.

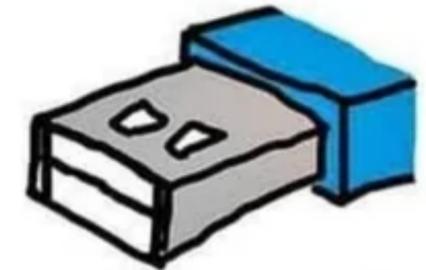
Up position



Down position

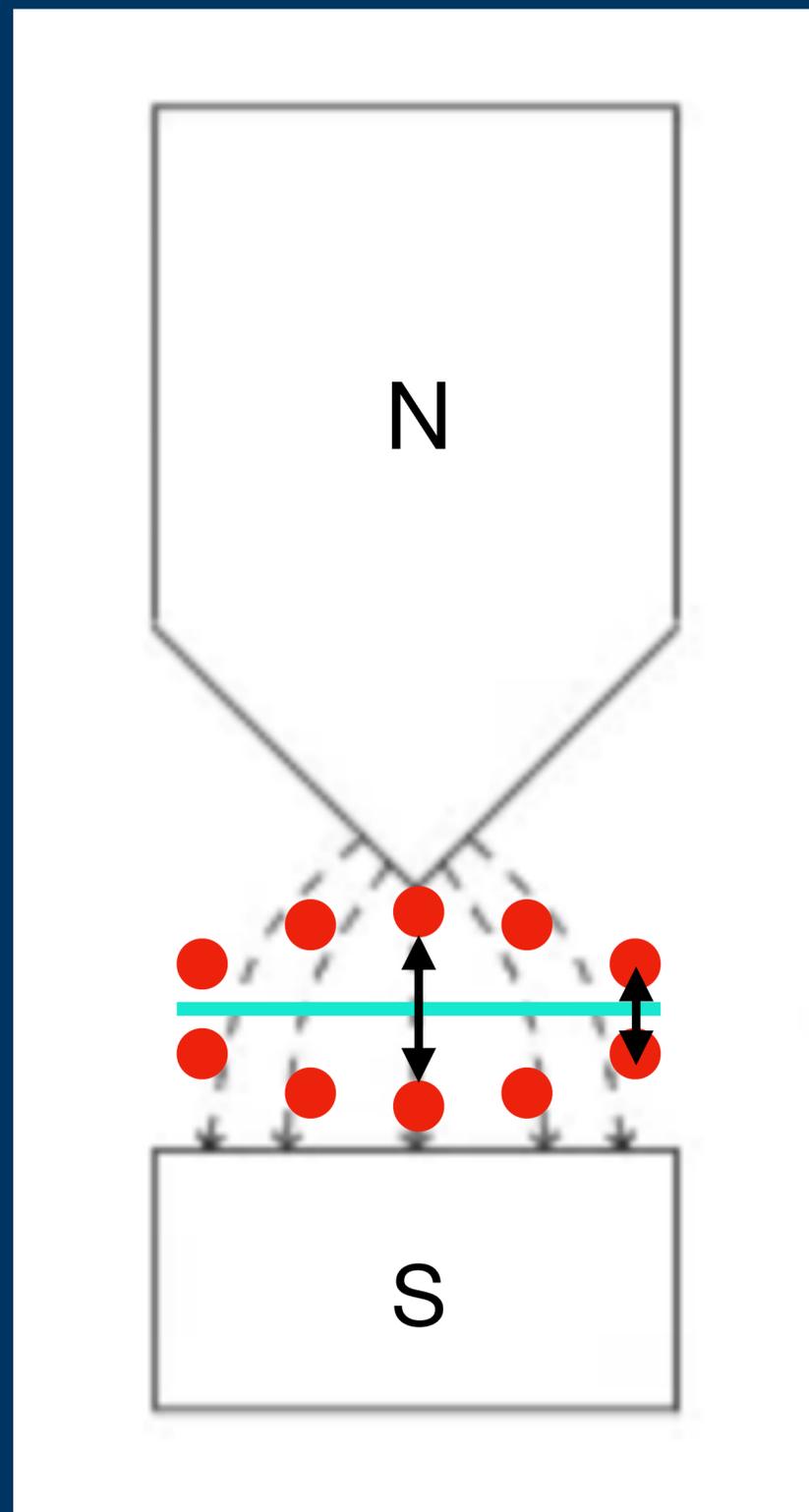


Superposition

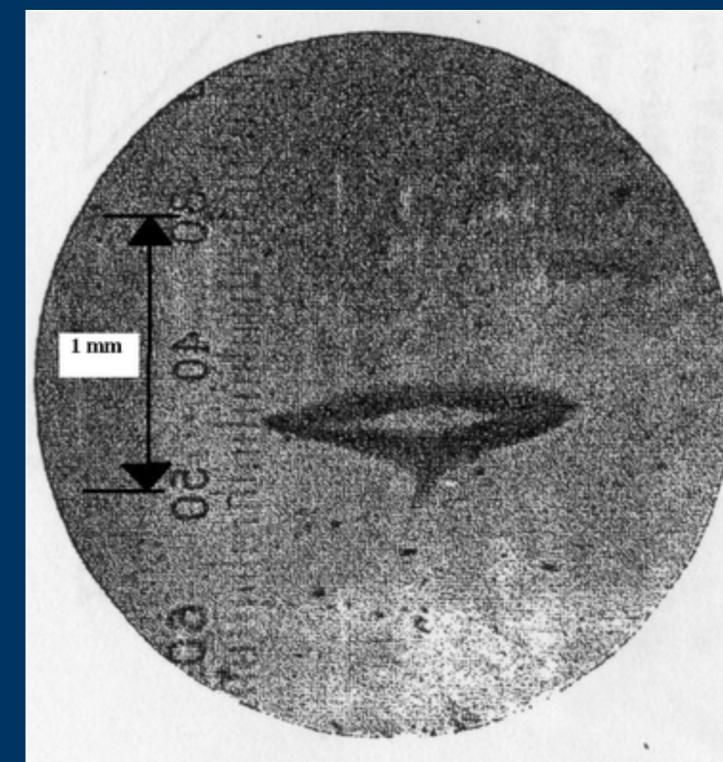


Until the USB is observed it will stay in the superposition. Therefore it will not fit until observed - except for in cases of USB tunnelling.

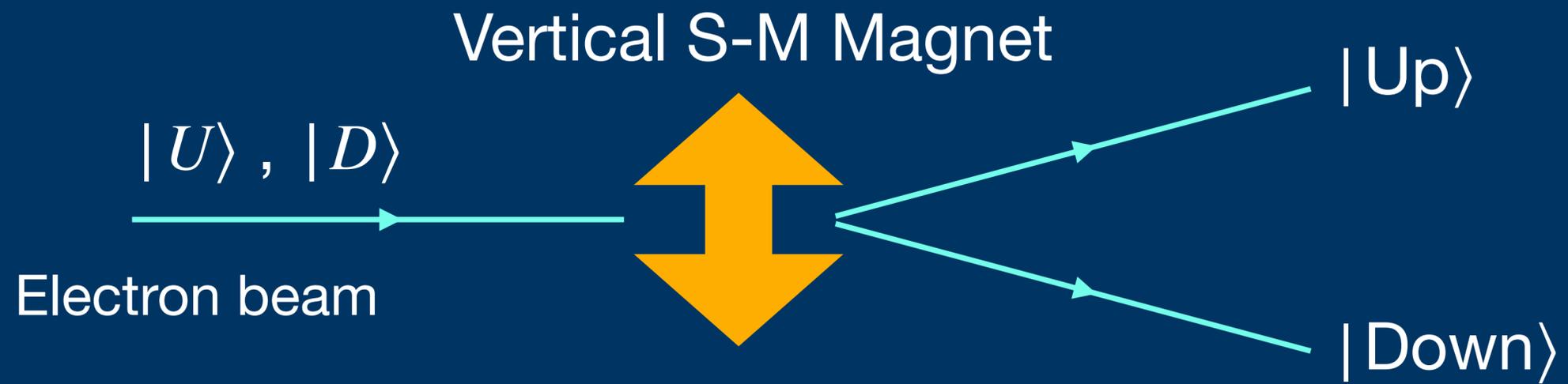
Electron beam has width



Get less deflection at edges where field is weakest



Gerlach, W.; Stern, O. (1922). "Der experimentelle Nachweis der Richtungsquantelung im Magnetfeld". Zeitschrift für Physik. 9 (1): 349–352

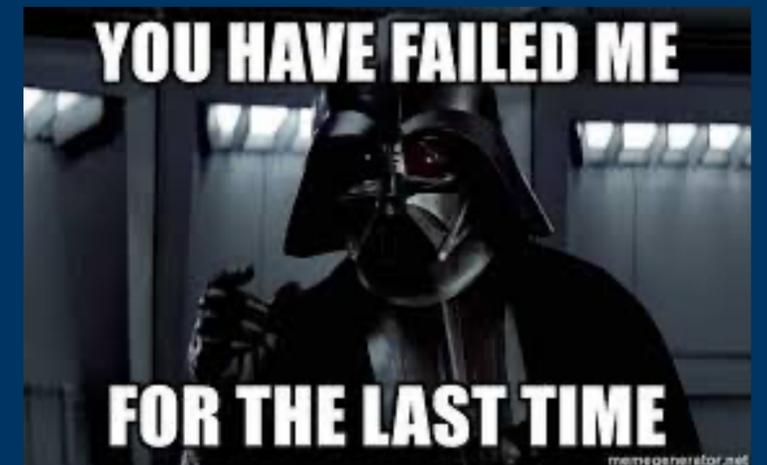


Electrons clearly come in 2 types

Call them 'up' electrons and 'down' electrons

Separated (sorted) by the magnet

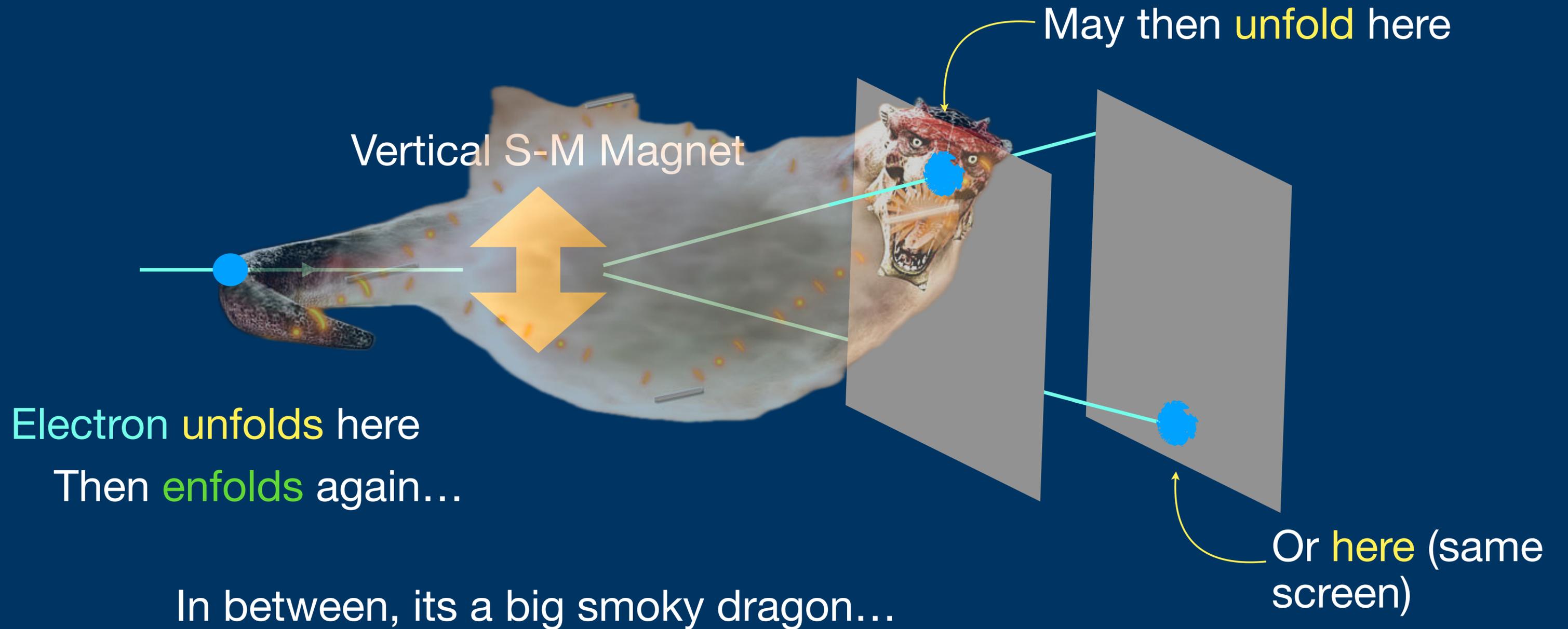
Original beam contains 50:50  $|U\rangle |D\rangle$



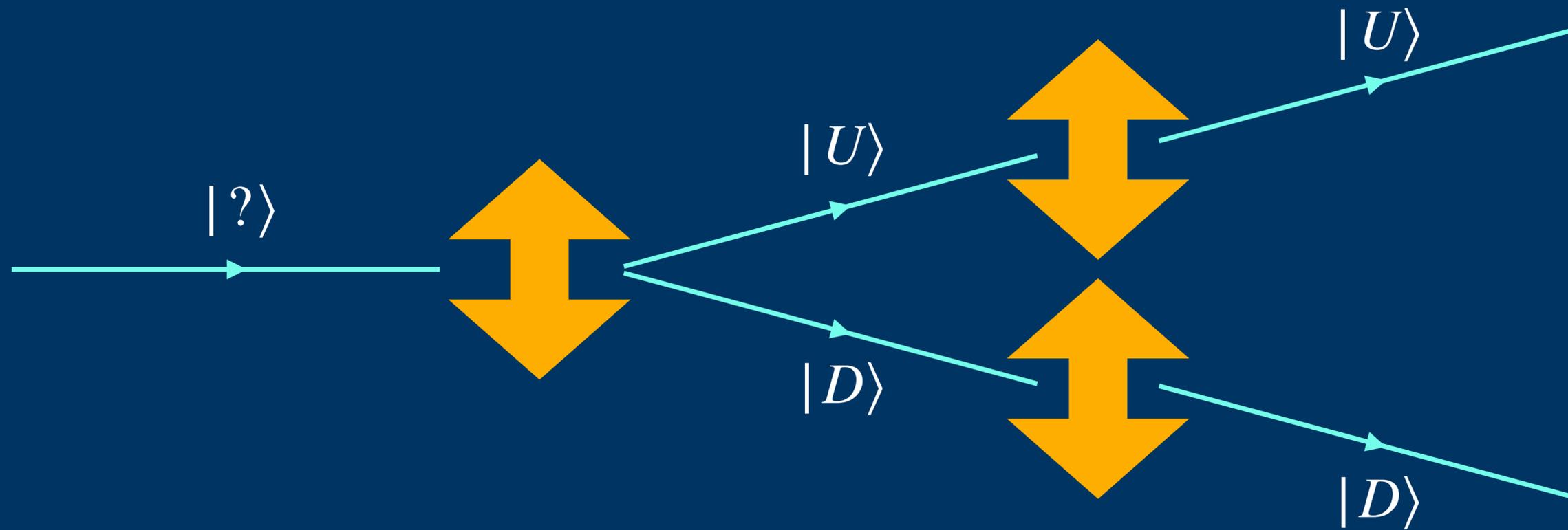
Full disclosure - this experiment can't be done with electrons - the Earth's magnetic field gets in the way.

There are no paths in QM!

# This is shorthand for...



# Check sorting....

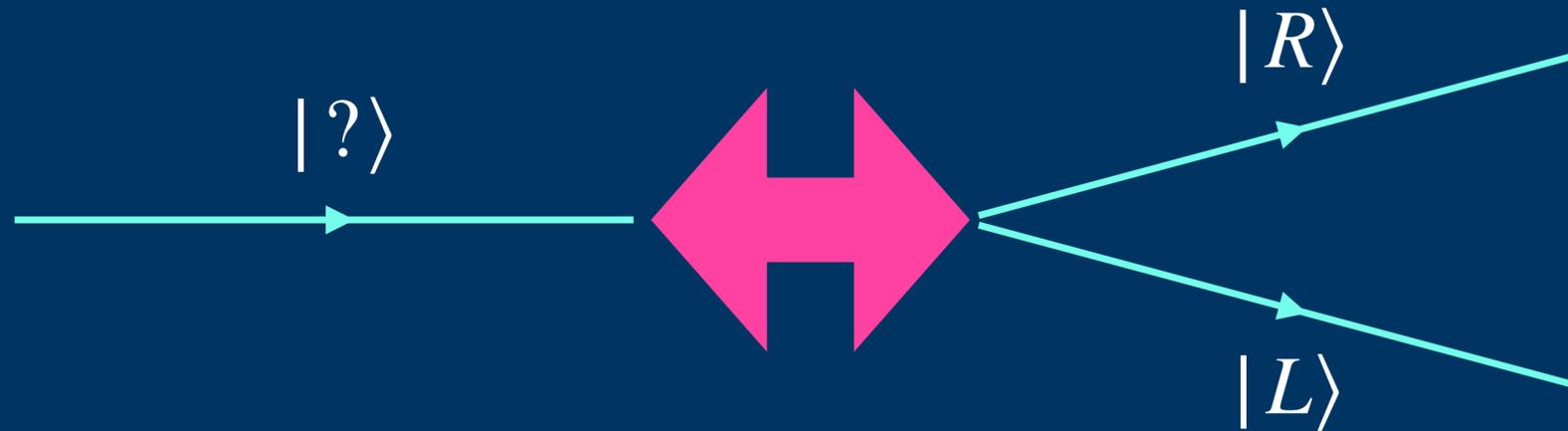


Once **sorted**, clearly **stay sorted**...



# But...

Horizontal S-M Magnet

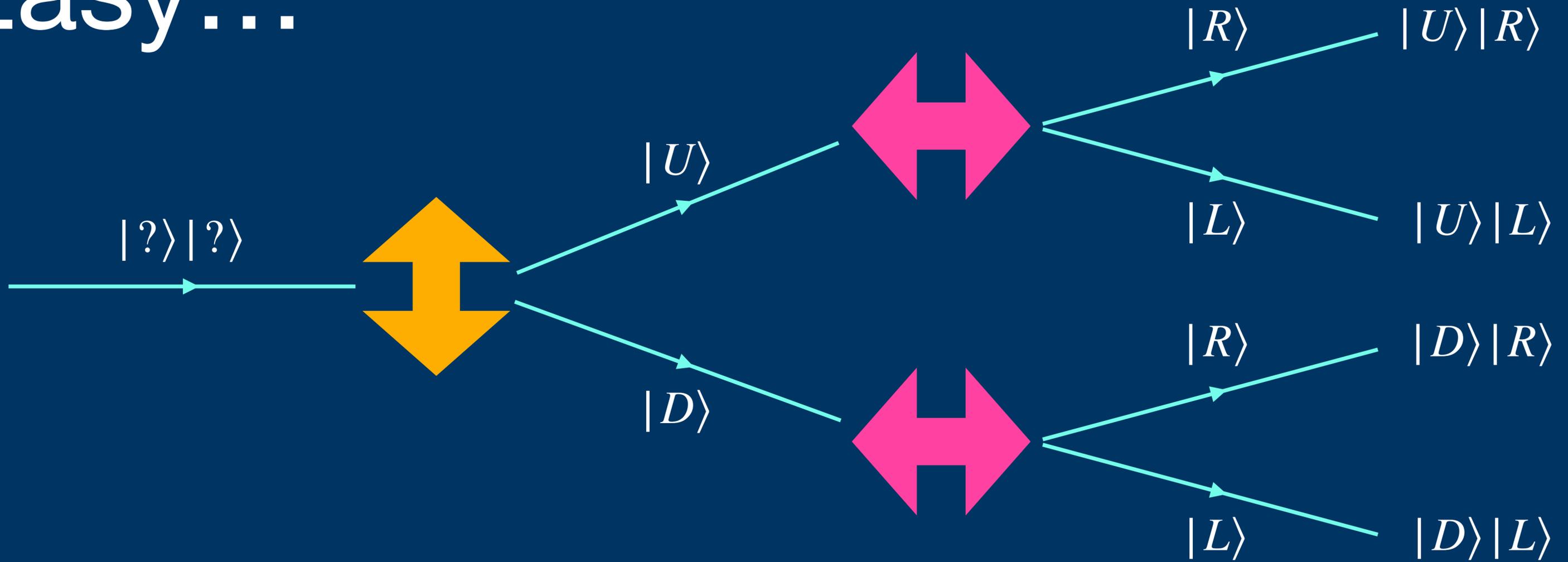


Why does vertical matter?

What if we **rotate** the magnet  $90^\circ$

We get **left** and **right** electrons...  $|L\rangle$   $|R\rangle$

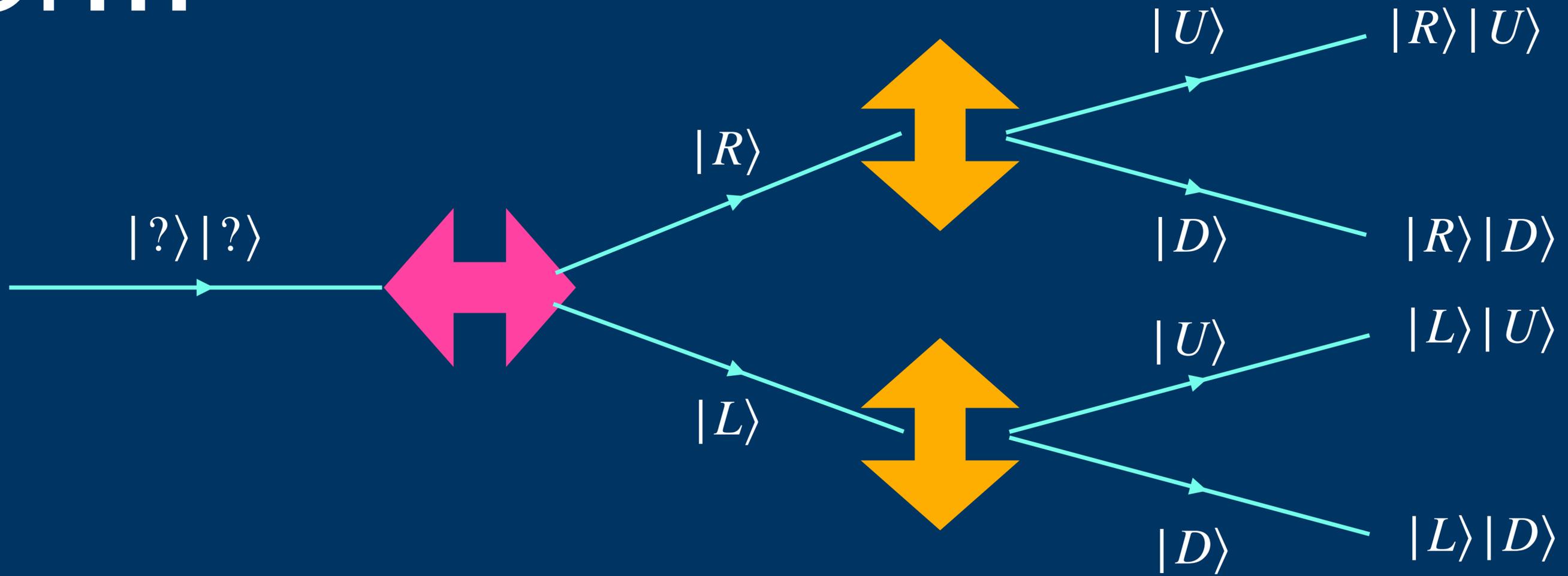
# Easy...



So we have **four types** of electron...



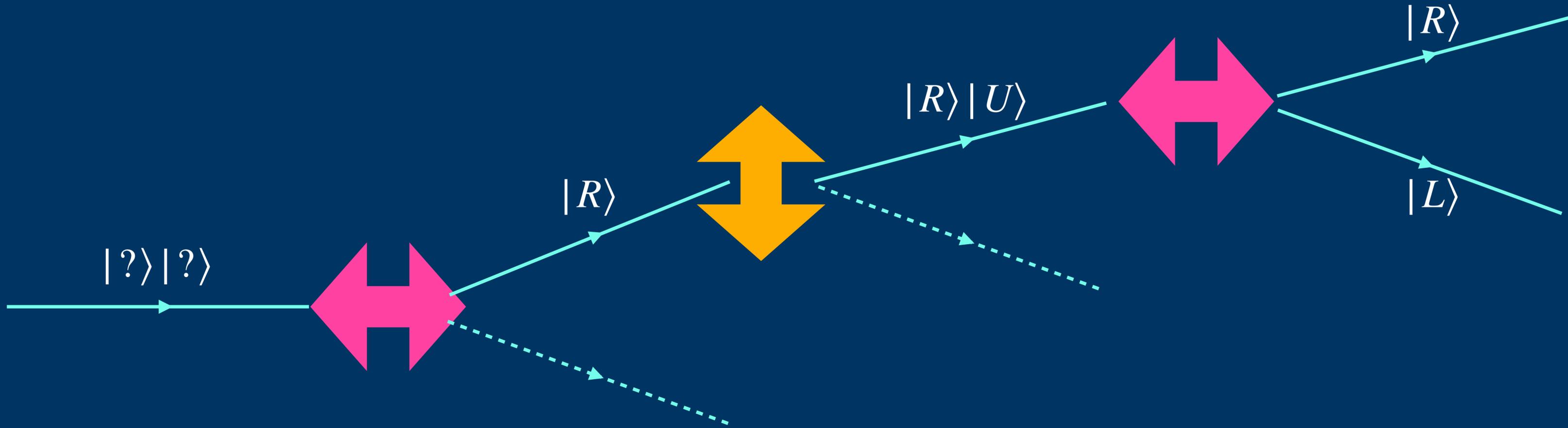
Or...



Confirms we are good!



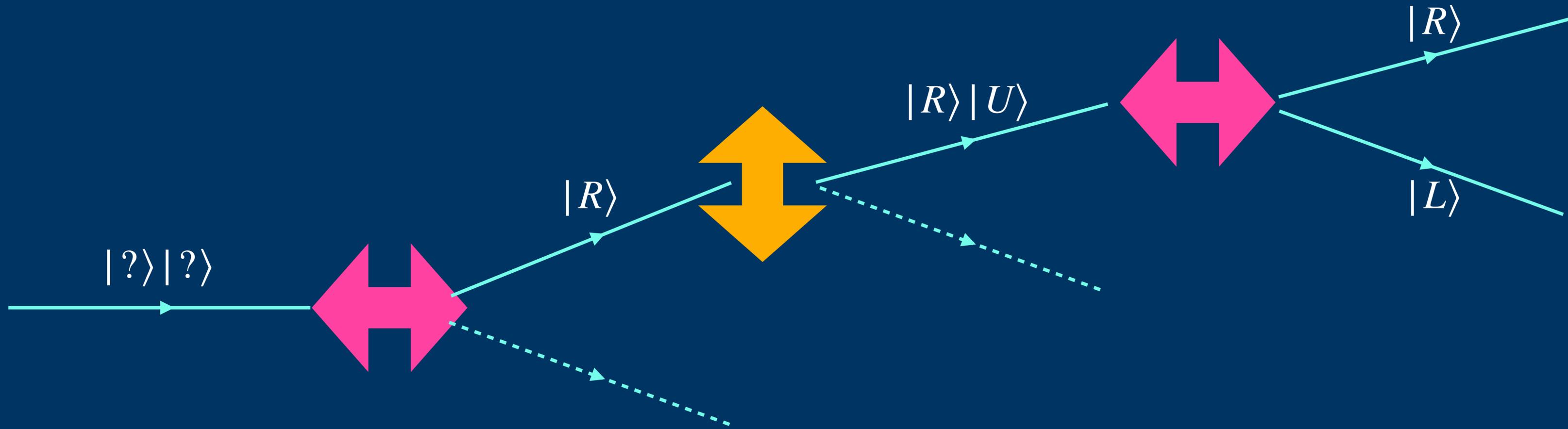
# Well...



Confirms we are **NOT** good!



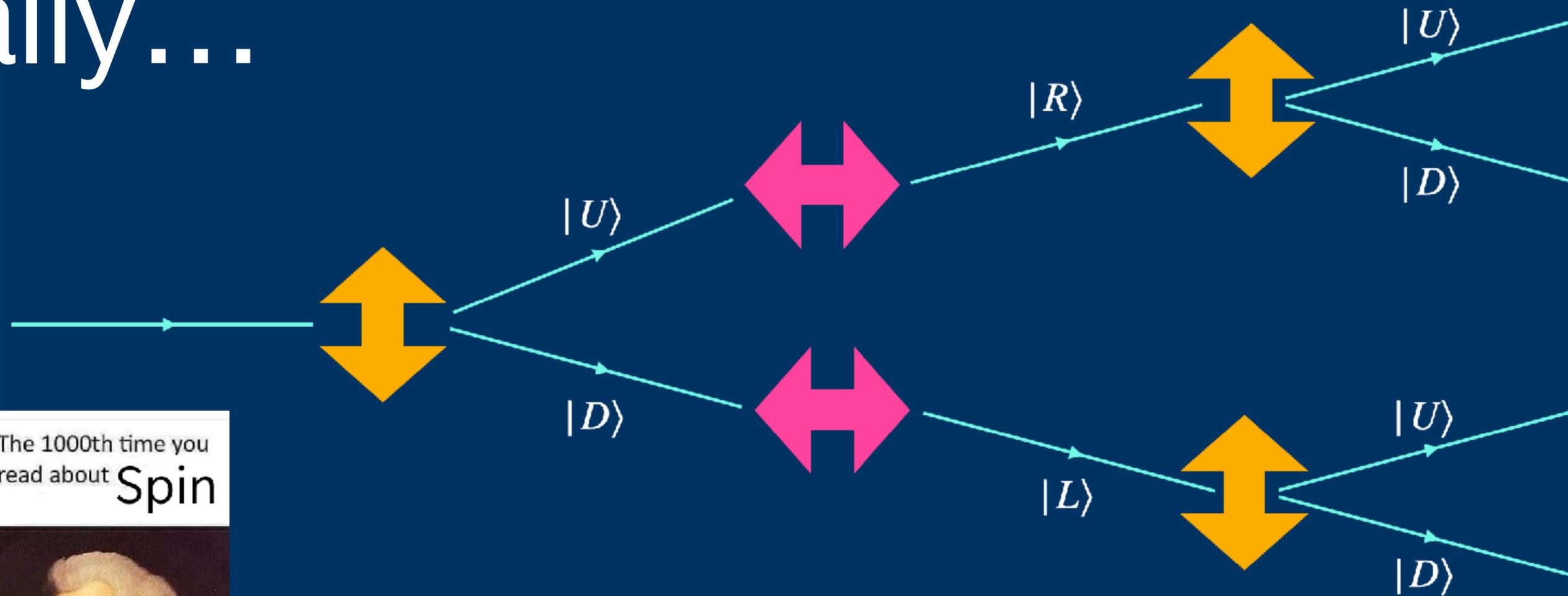
# Well...



Confirms we are **NOT** good!

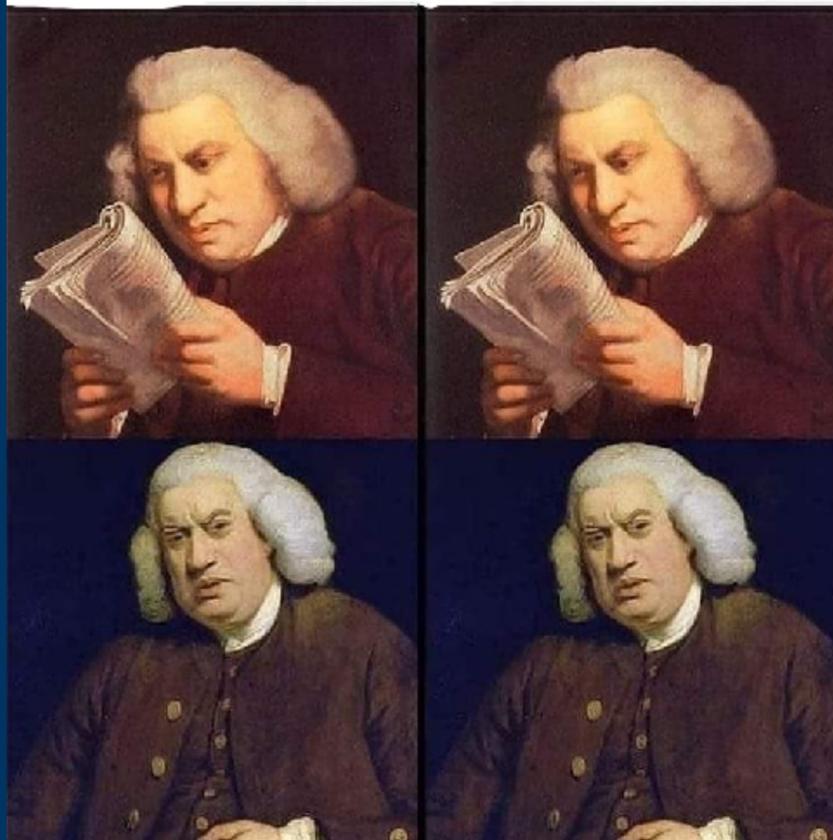


# Equally...



The first time you read about Spin

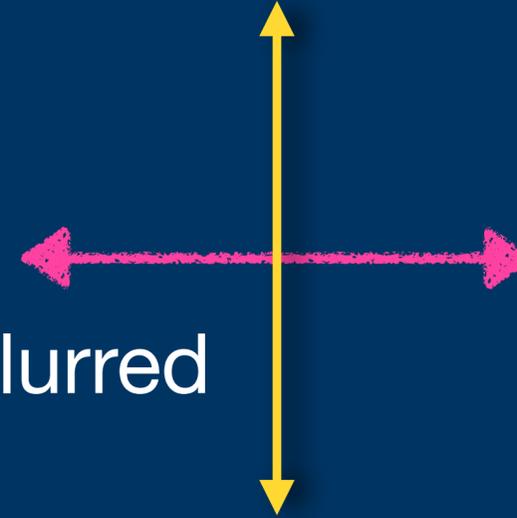
The 1000th time you read about Spin





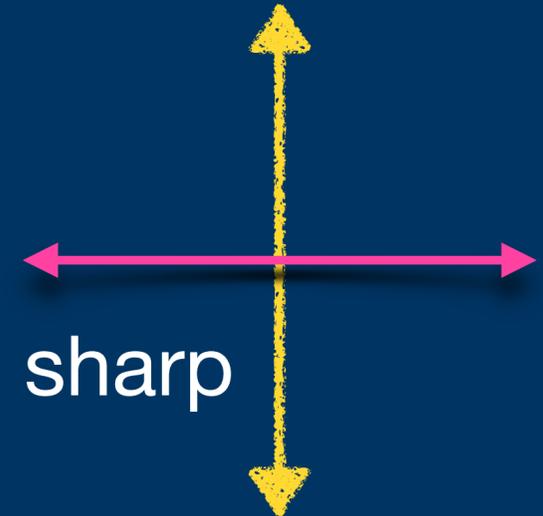
HERE

Vertical sharp



Horizontal blurred

Vertical blurred



Horizontal sharp

But its really **worse** than 'blurred'

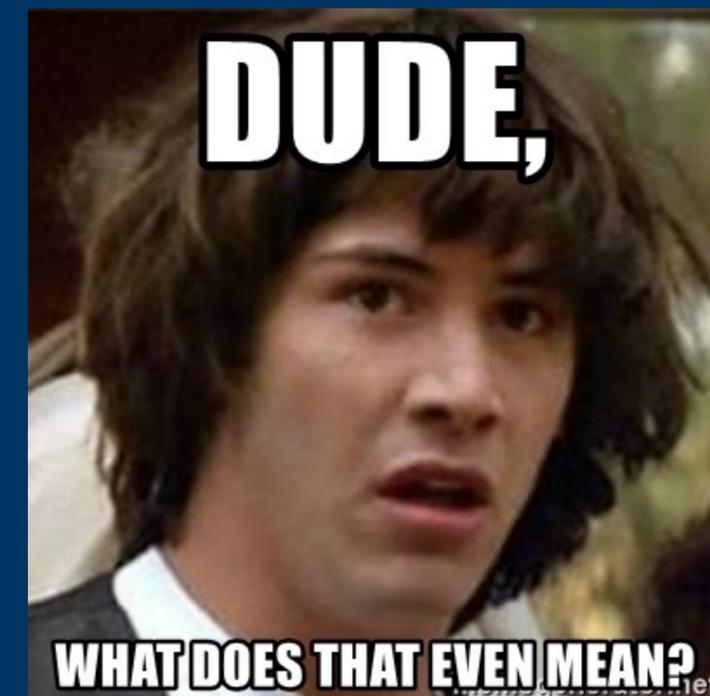
One direction's spin **does not exist**

If the **other** is manifest...

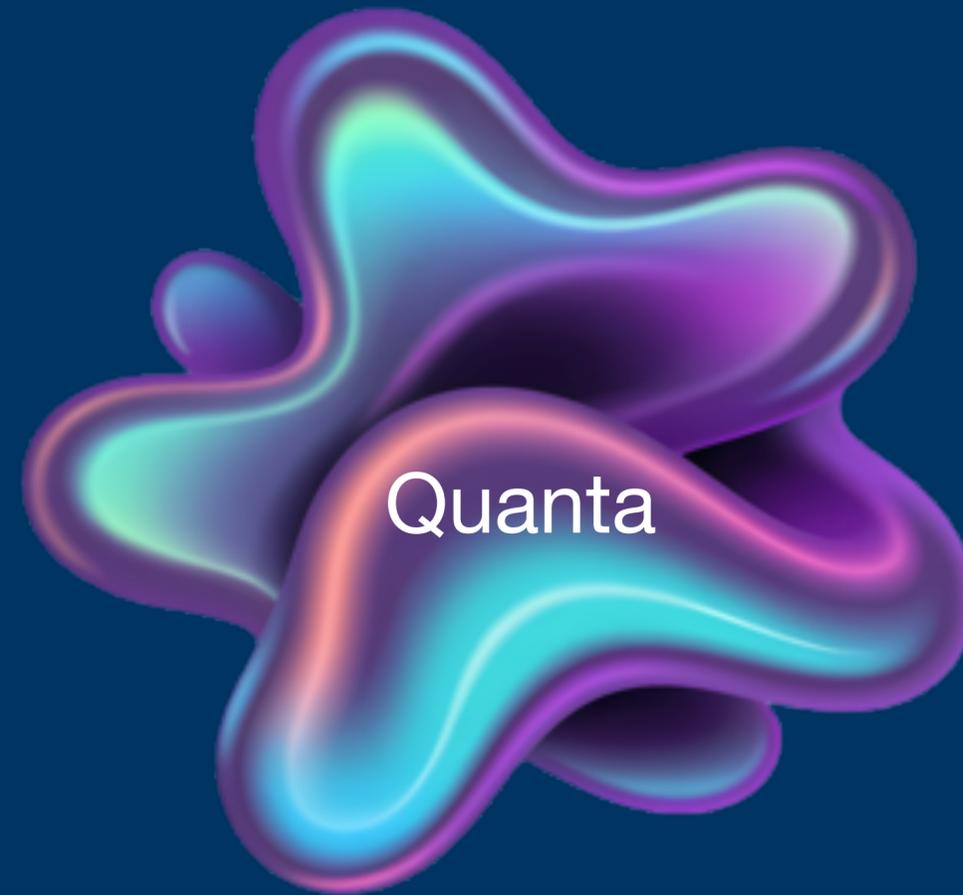


# Bohr

The **quantum postulate** forces us to adopt a **new mode of description** designated as **complementary** in the sense that any given application of **classical concepts precludes** the **simultaneous use of other classical concepts** which in a different connection are **equally necessary** for the elucidation of phenomena.

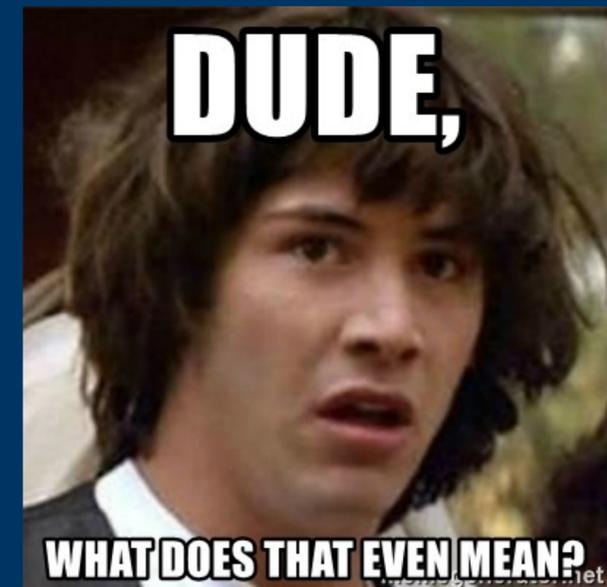


Have no concepts to completely describe quanta



Only directly experience the outcome

When they unfold into our classical world



Our **concepts** are **forged** in the **classical world**

Our **language** works in that world

**Classical concepts** do not apply to **quanta**

Have to **improvise**..



Have no concepts to completely describe quanta

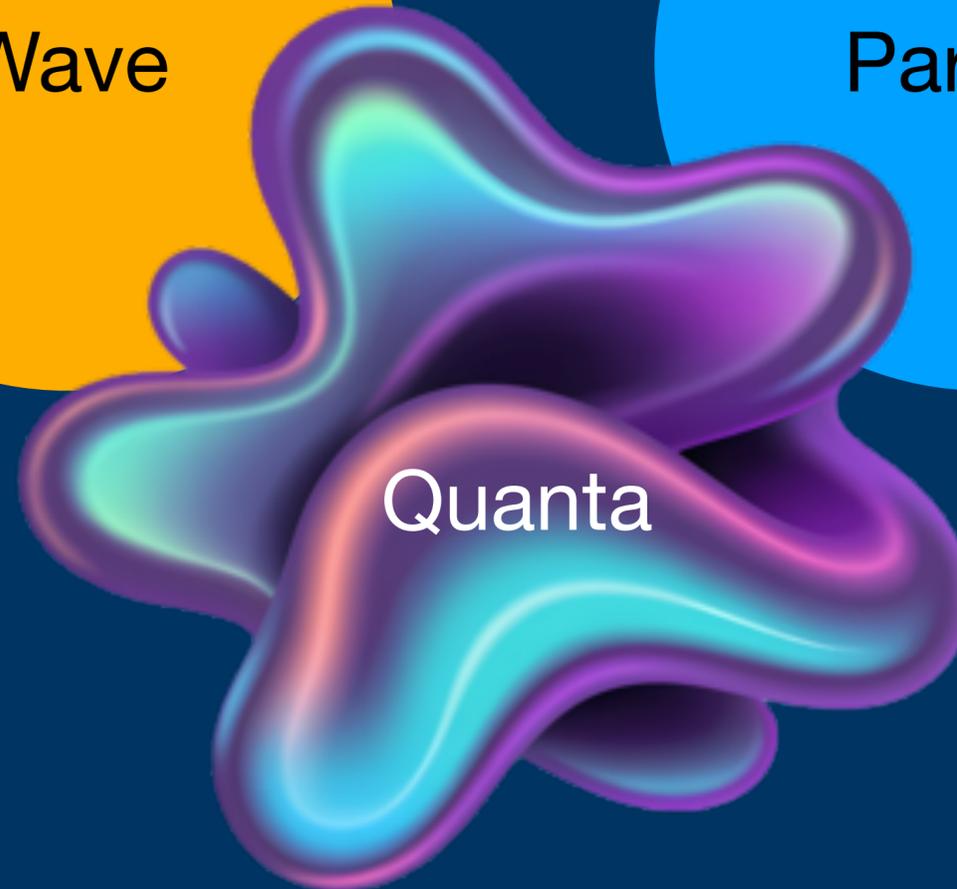
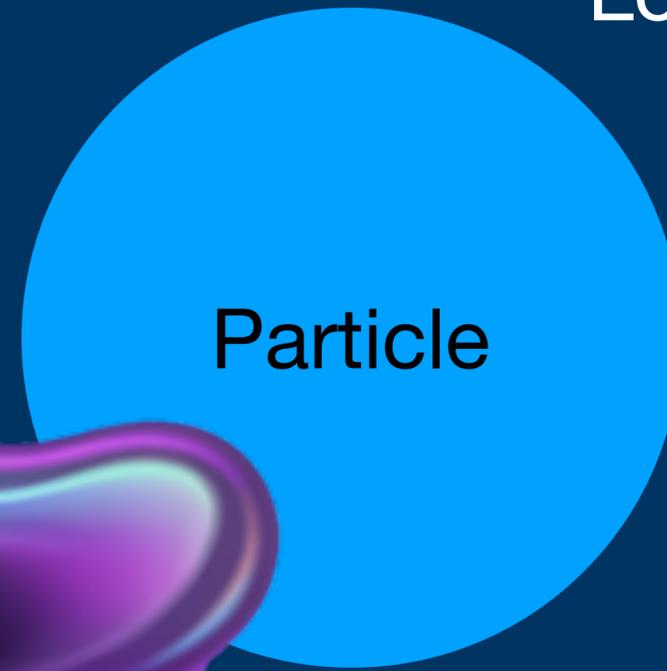
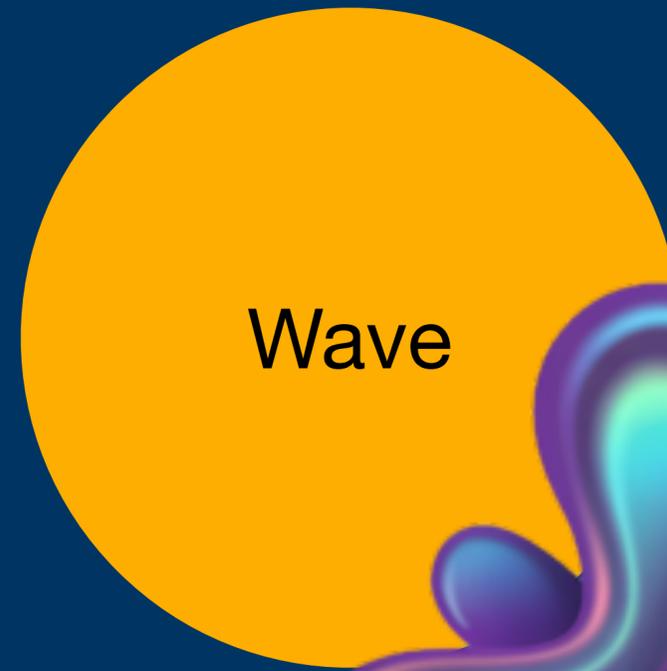
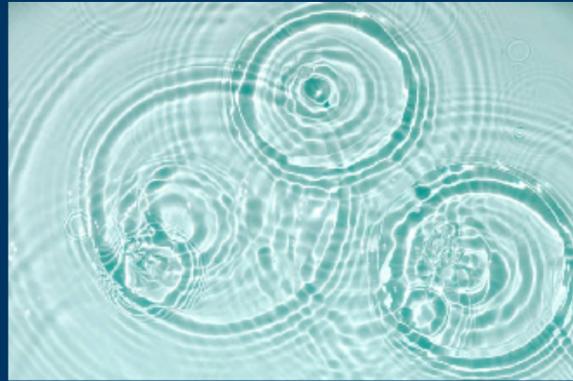
One classical idea

Another classical idea

But (fortunately) not both at the same time

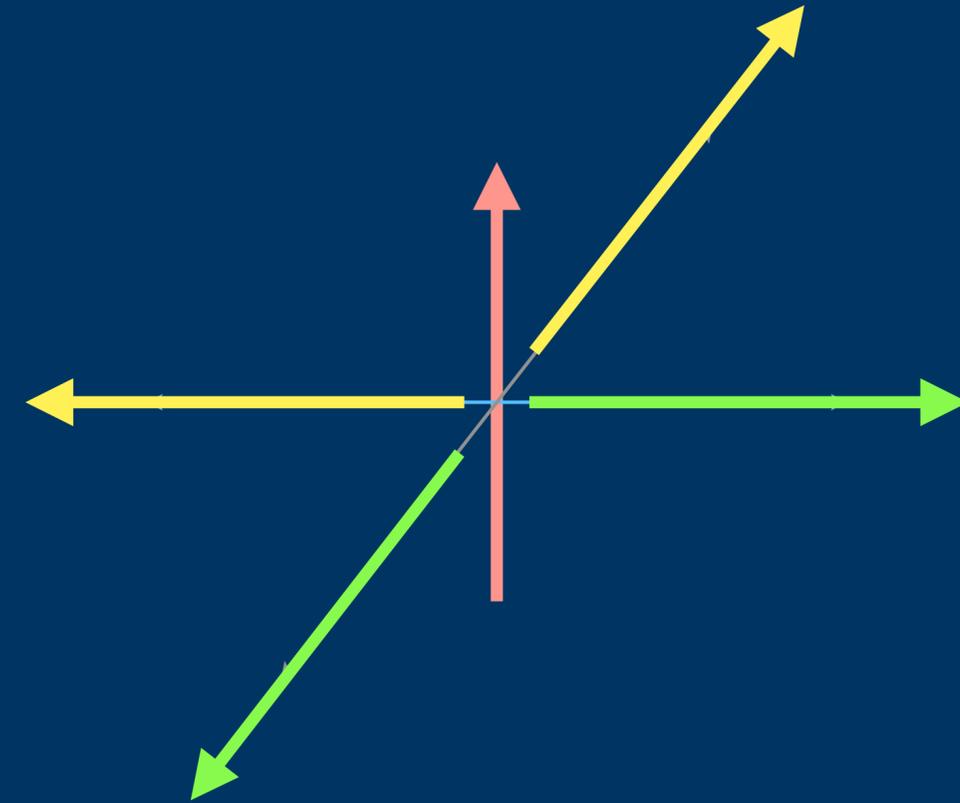
Spread out and flappy

Localised and rigid



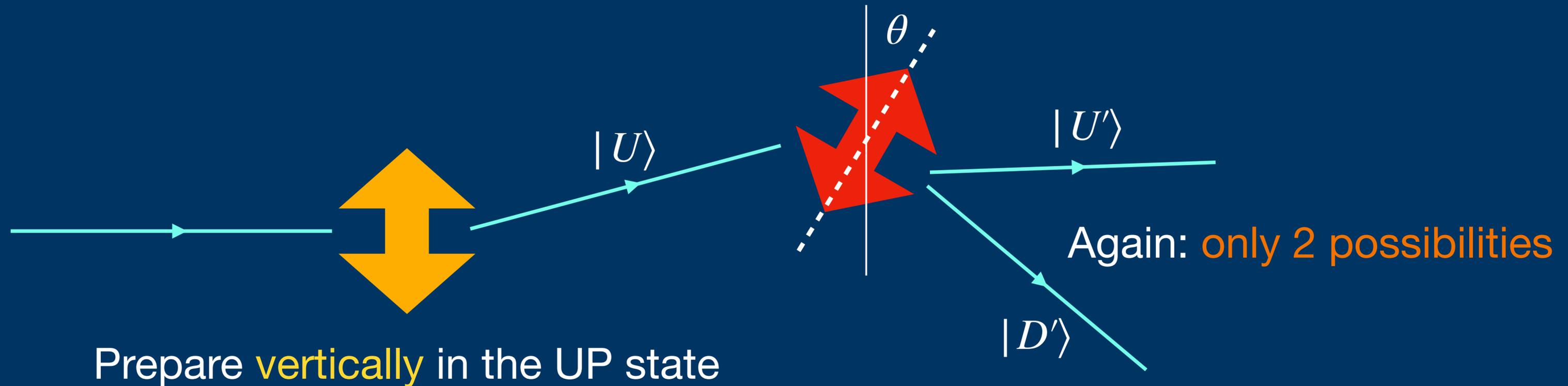
# Important question...

- Isolate the (e.g.) top beam
  - All electrons in UP state  $| + 1 \rangle$
- Send through a L/R magnet
  - What happens?
    - 50% come out LEFT
    - 50% come out RIGHT
- Send through a magnet at another angle
  - Some come out UP
  - Some come DOWN } Along the magnet angle
  - Fraction of each depends on the angle



# Intermediate Angles

Measure at some intermediate angle



Prepare vertically in the UP state

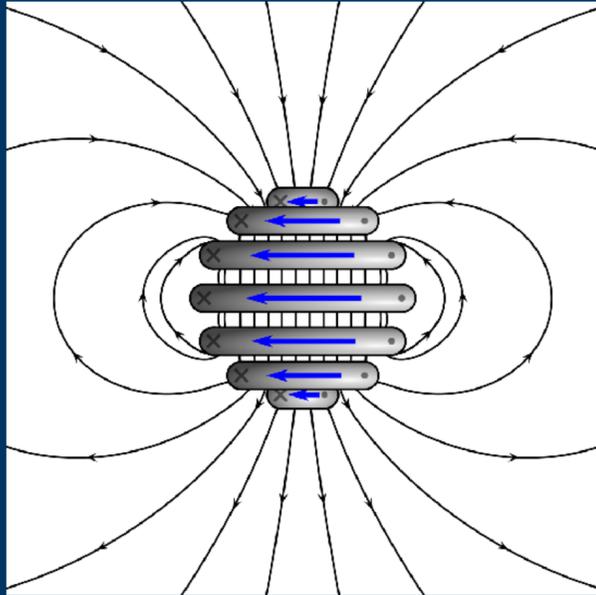
Again: only 2 possibilities

If  $\theta = 30^\circ$   
 $|U'\rangle \rightarrow 93.4\%$   
 $|D'\rangle \rightarrow 6.7\%$

$$|U'\rangle \sim \cos^2(\theta/2)$$

$$|D'\rangle \sim \sin^2(\theta/2)$$

# So what is spin???

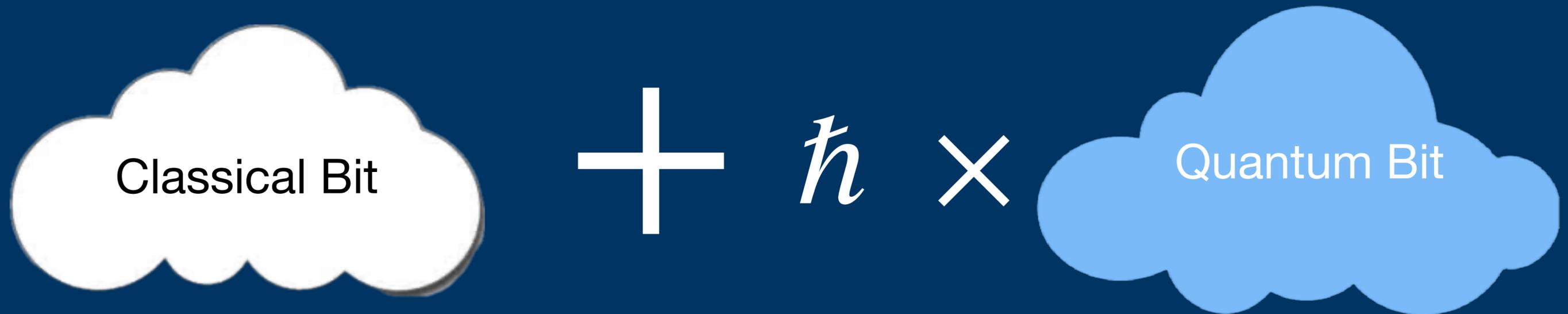


	Spinning charged sphere	Electron
Charge	Any	Fixed
Spin rate	Any	Fixed
Spin Axis	Any	Always Up or Down along external axis
Magnetic Field	Dependent on rate	Fixed

Not a classical idea

# H-bar

Fundamental constant - the 'scale' of quantum effects



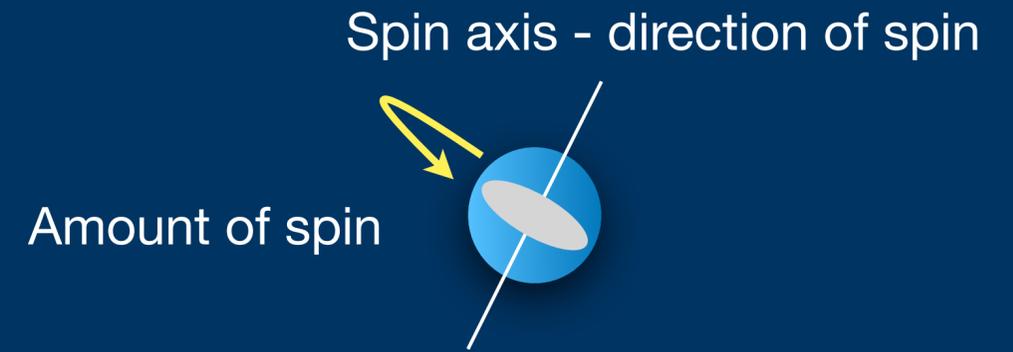
Imagine letting  $\hbar \rightarrow 0$

Should restore classical physics

$$\hbar = 1.055 \times 10^{-34} \text{ Js}$$

# Spin

Amount of spin:  $\frac{\sqrt{3}}{2}\hbar$

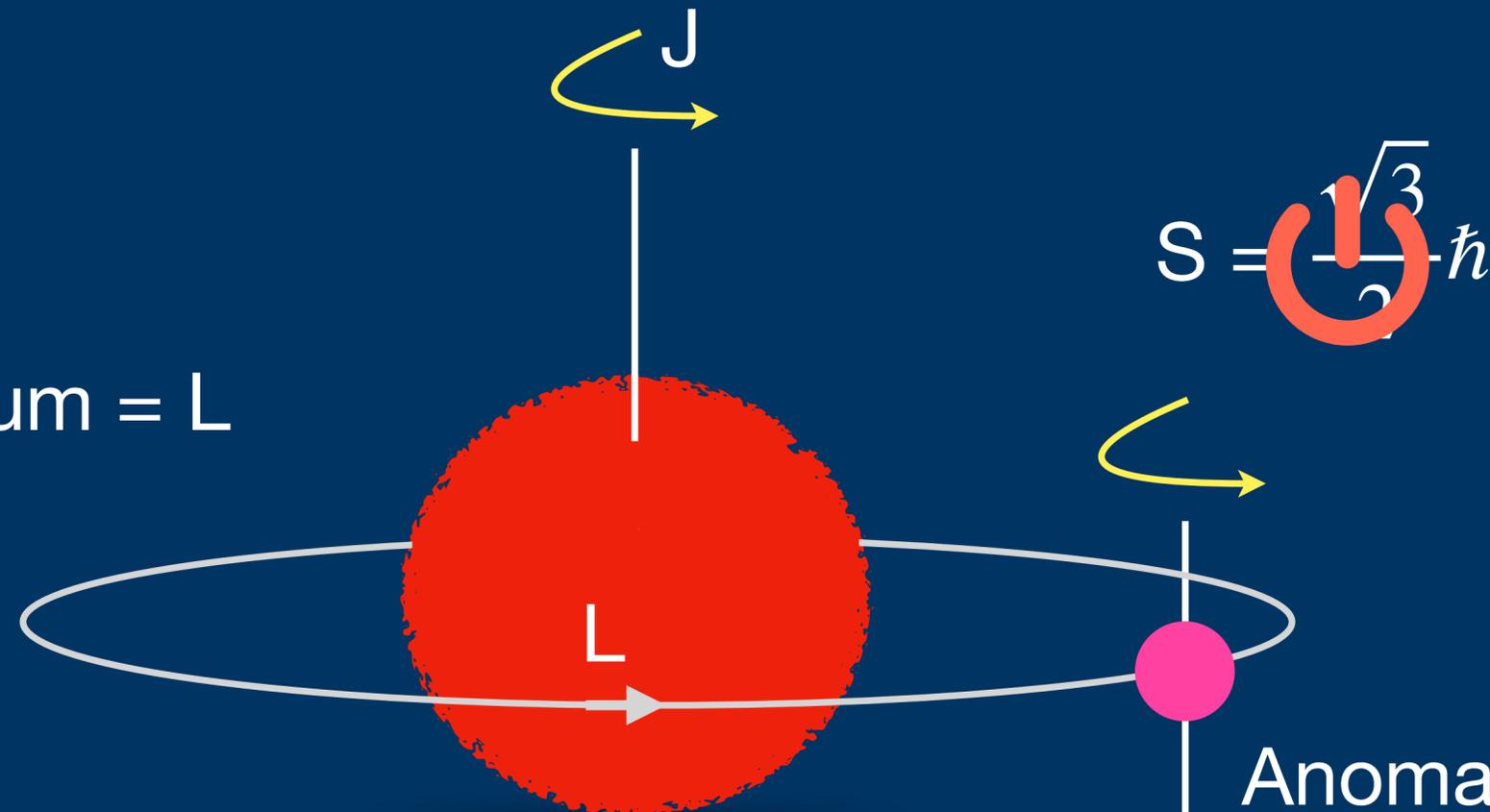


+  $\hbar$  ×



Nothing left if we let  $\hbar \rightarrow 0$

Orbital angular momentum =  $L$



Anomalous Phenomenon...

Total angular momentum,  $J = L + S$

$\hbar \rightarrow 0$

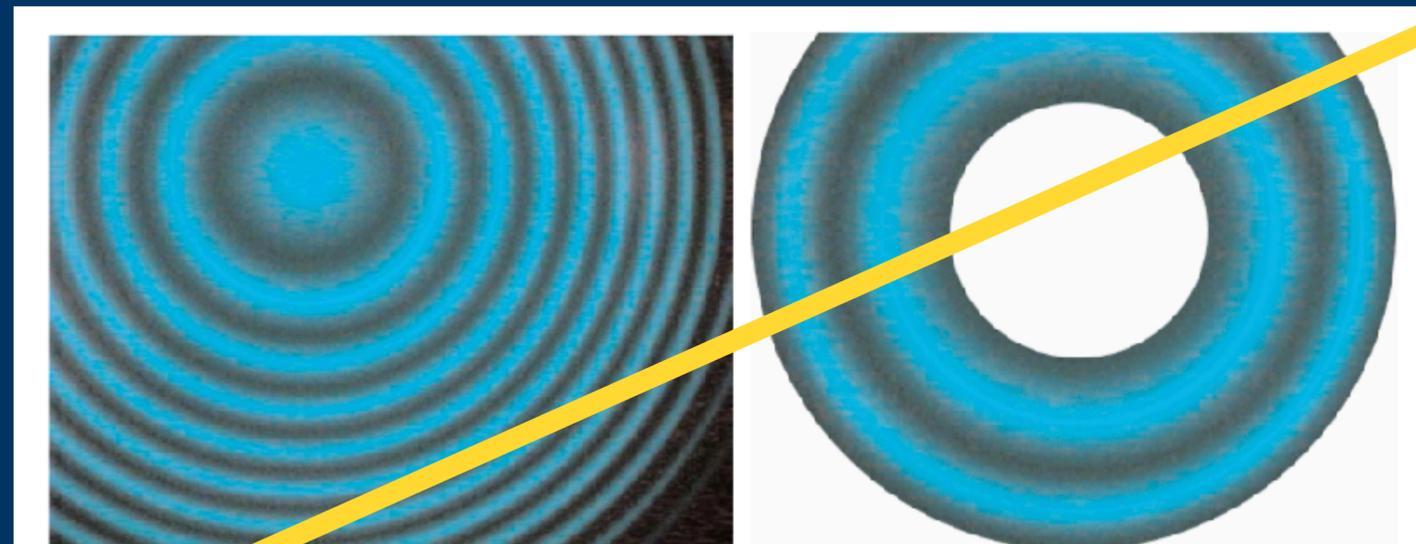


Fig. 12: Anomalous Zeeman effect: Interference pattern with horizontal polarization filter and magnified cut-out of the first complete two orders



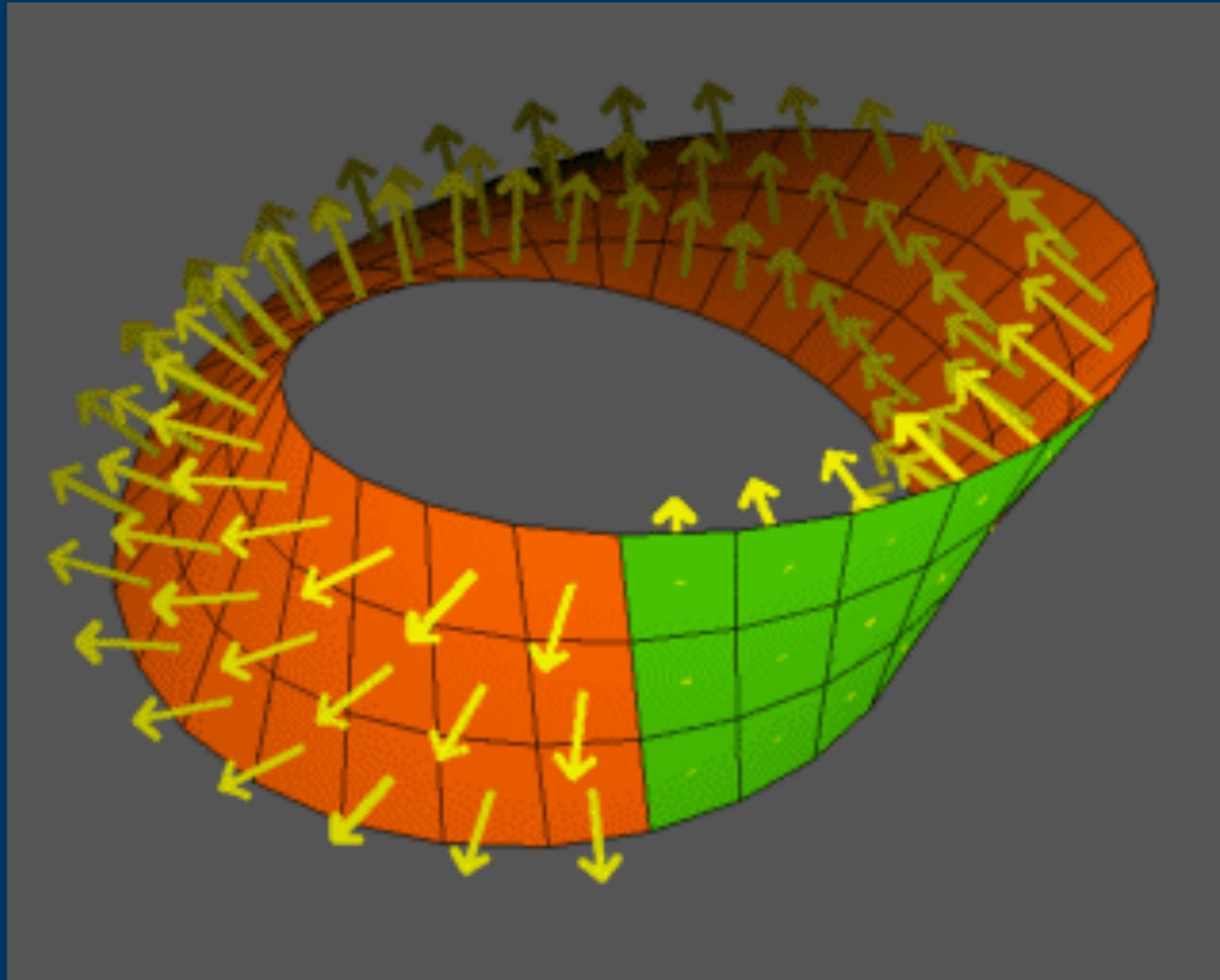
# So, conclusion?

Spin is a **property** of the **big smoky dragon**...

It's how the **wave function reacts**

If you try and **rotate a particle**...





Clear in the **mathematics**

Our **classical concepts** fail us...

Orientation on a Möbius strip..



If you aren't confused by quantum mechanics, you haven't really understood it.

— Niels Bohr —

AZ QUOTES

in conclusion, i have absolutely no idea what i'm talking about.



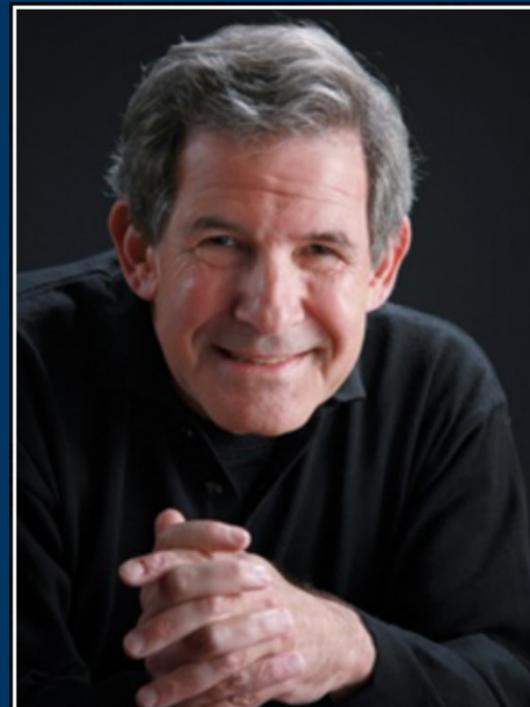
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It is often stated that of all the theories proposed in this century, the silliest is quantum theory. In fact, some say that the only thing that quantum theory has going for it is that it is unquestionably correct.

— Michio Kaku —

AZ QUOTES



According to quantum field theory, fields alone are real. They are the substance of the universe and not 'matter'. Matter is simply the momentary manifestation of interacting fields which, intangible and insubstantial as they are, are the only real things in the universe.

— Gary Zukav —

AZ QUOTES



-Remember, Fainsworth: to catch a deranged quantum physicist, you have to *think* like a deranged quantum physicist.