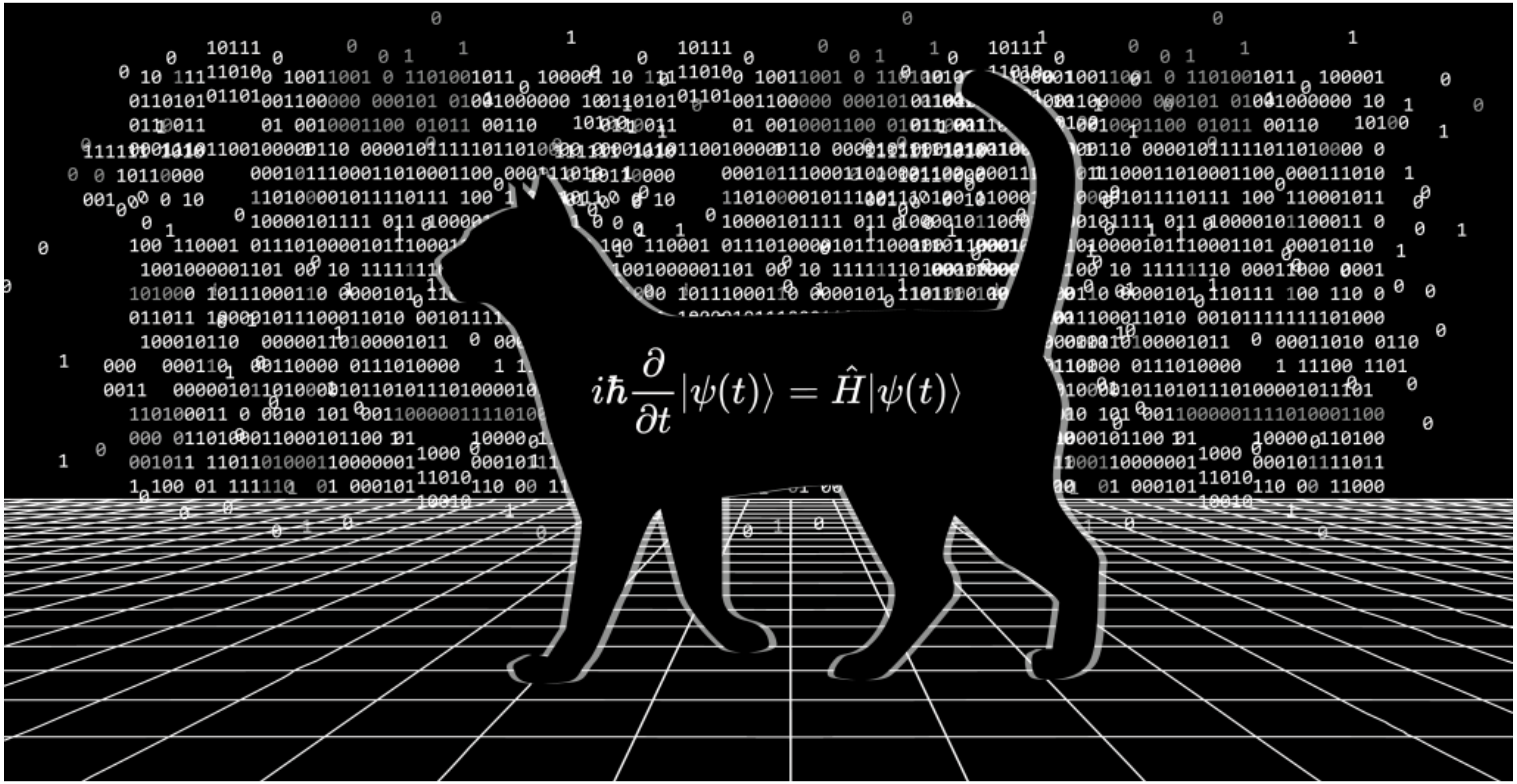
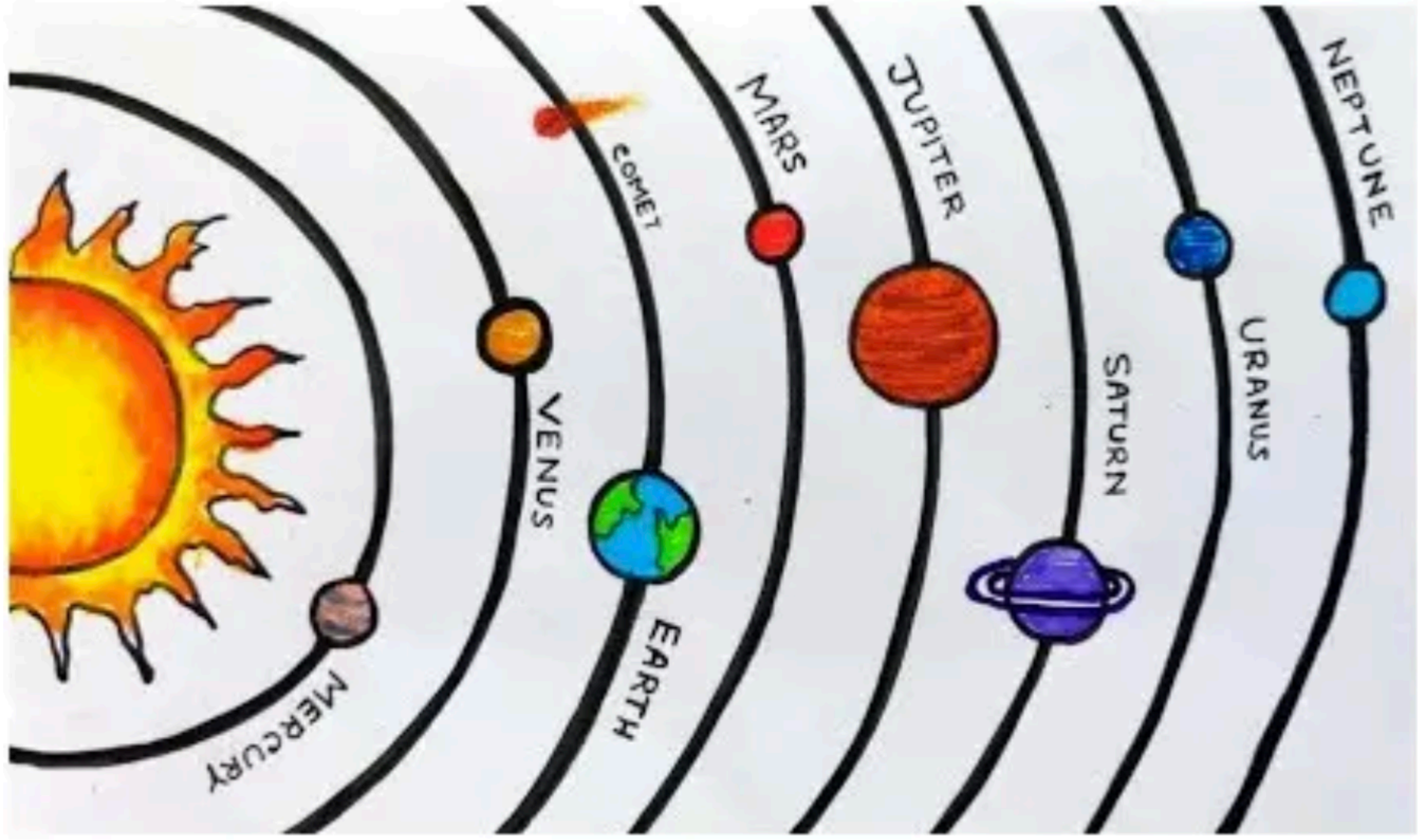
PHYS-344: **QUANTUM** MECHANICS FOR **NON-PHYSICISTS**

Prerequisites: working knowledge of complex numbers, linear algebra, calculus & differential equations. Knowing a little physics helps but **not required**.



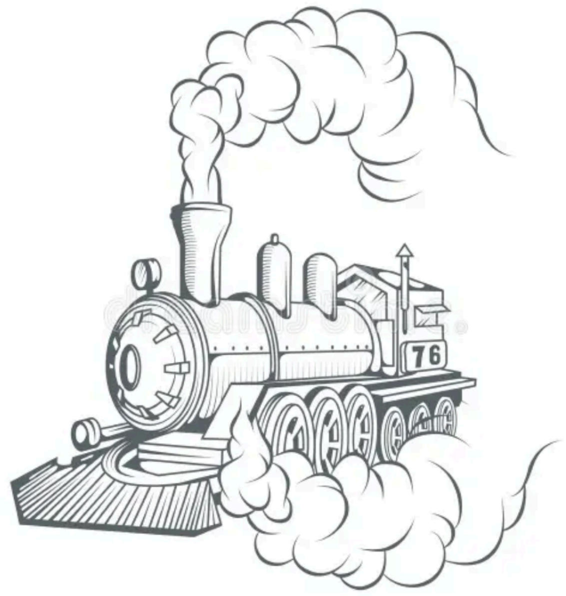
Instructor: Prof. Vladimir Manucharyan (EPFL - SB - SQIL)

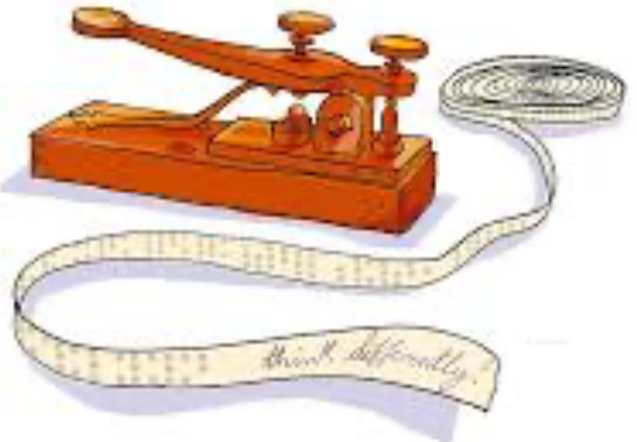
Classical vs quantum

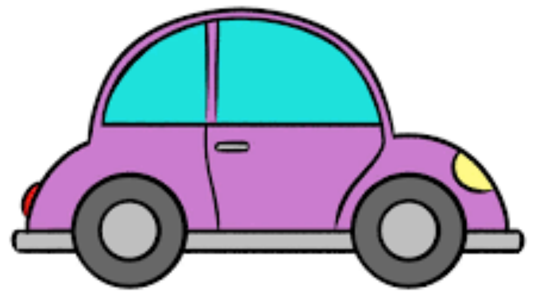


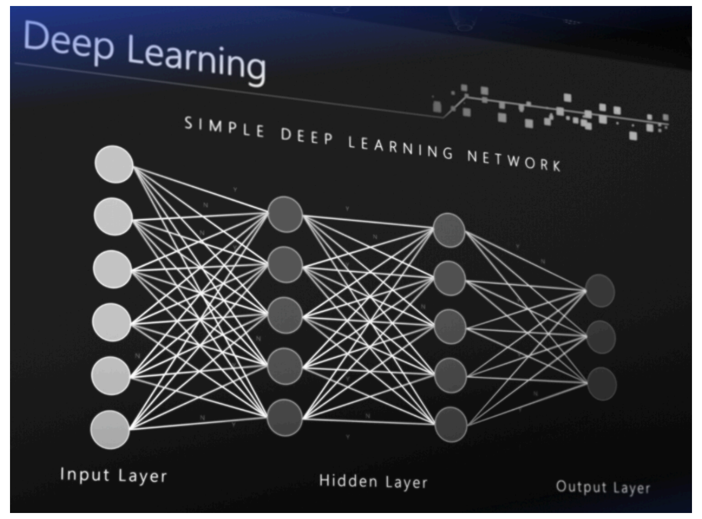
Mechanics/Thermodynamics

Electromagnetism



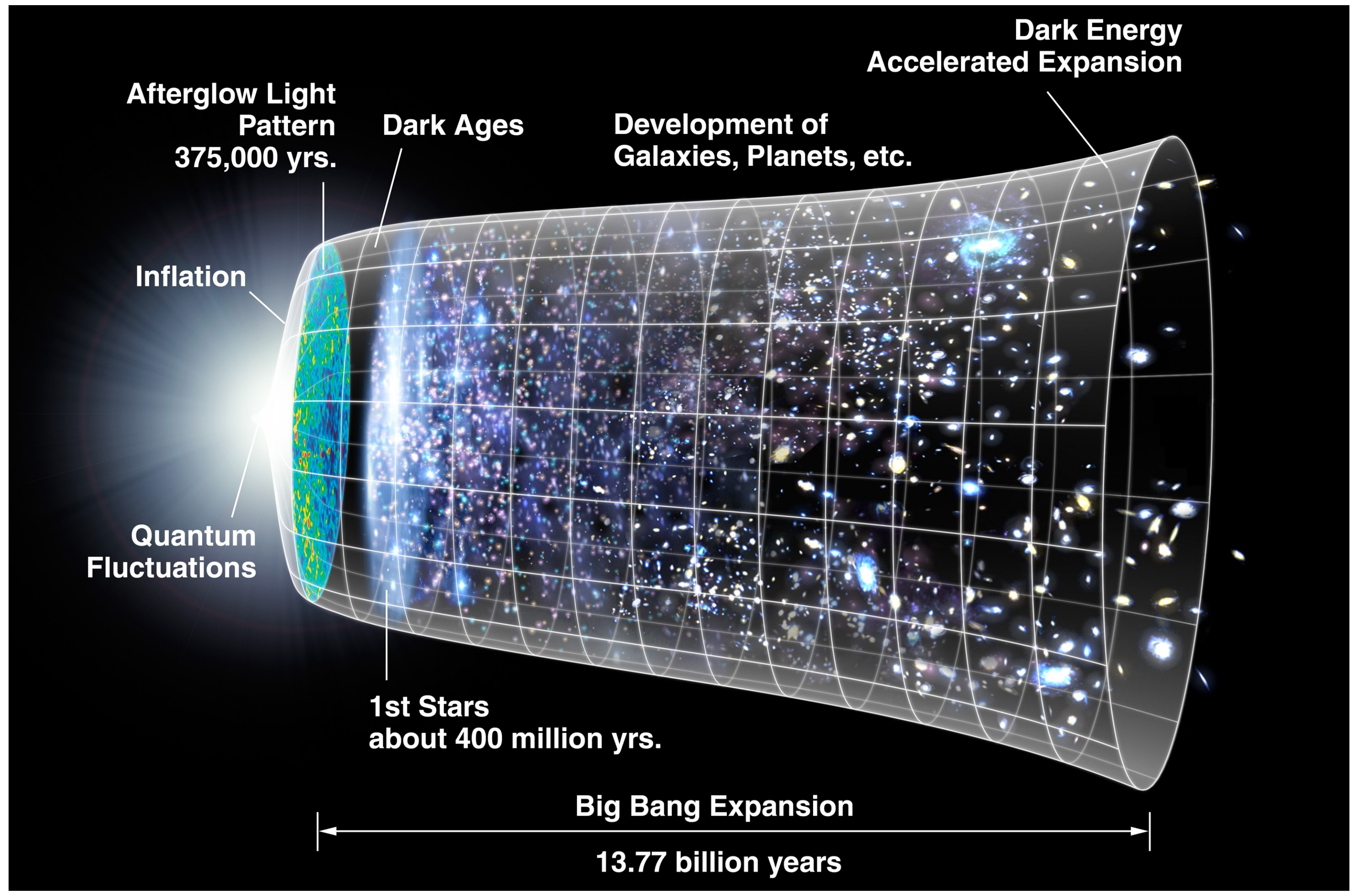


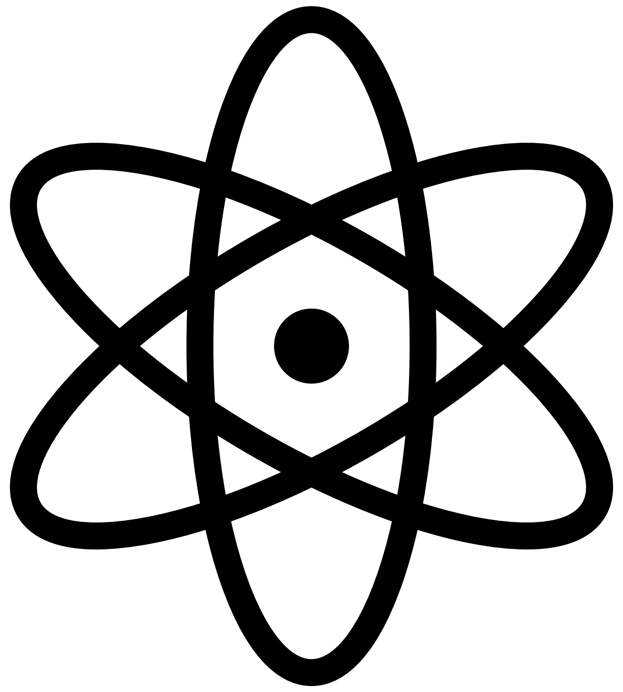




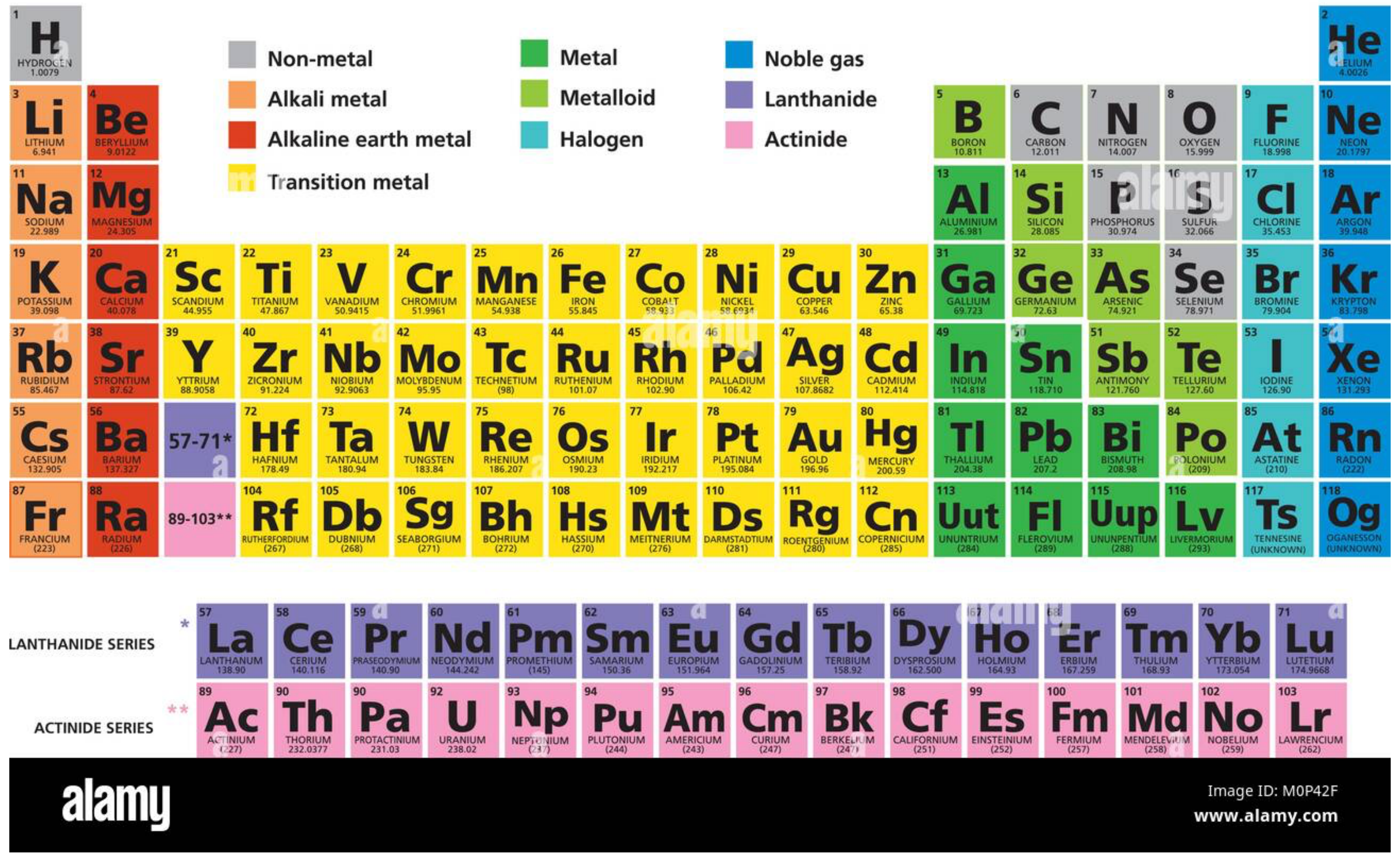
Classical vs **quantum**

Big Bang theory

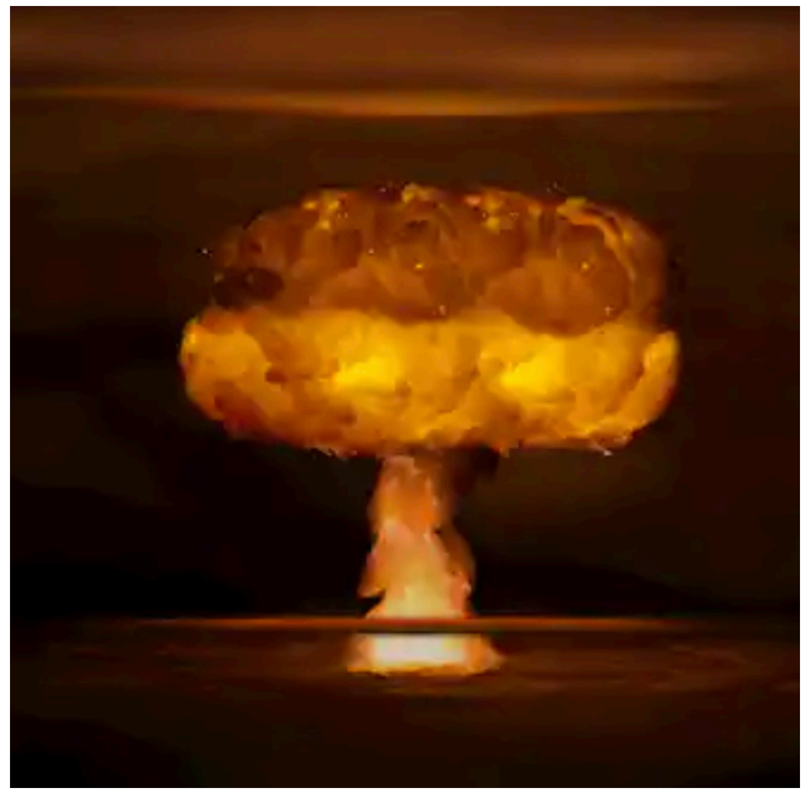




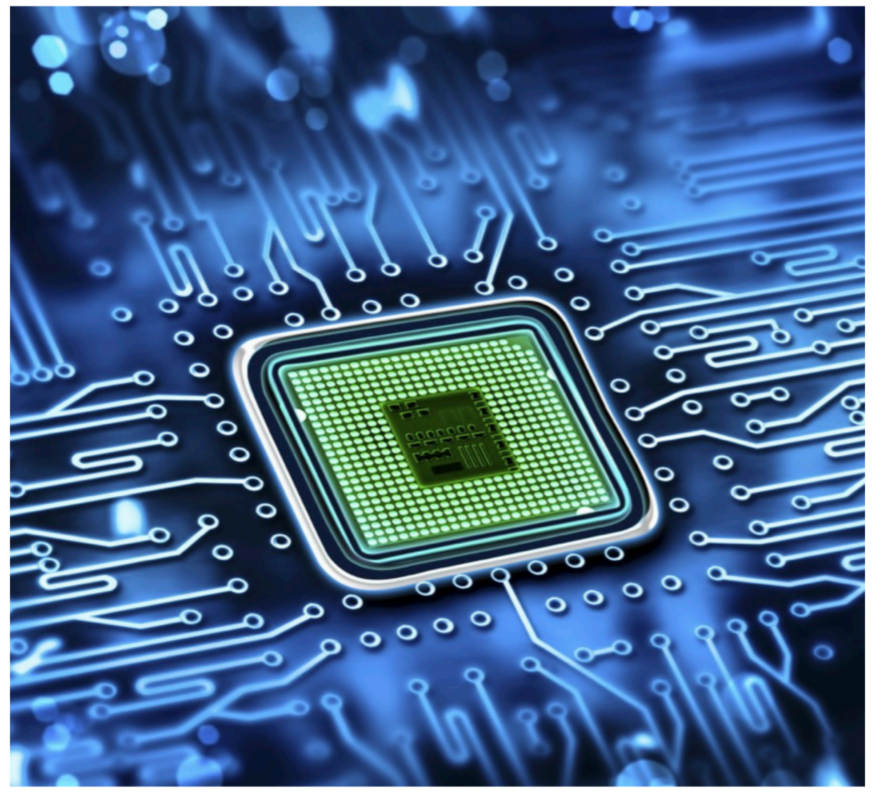
Periodic table



Nuclear energy



Electronics



Lasers

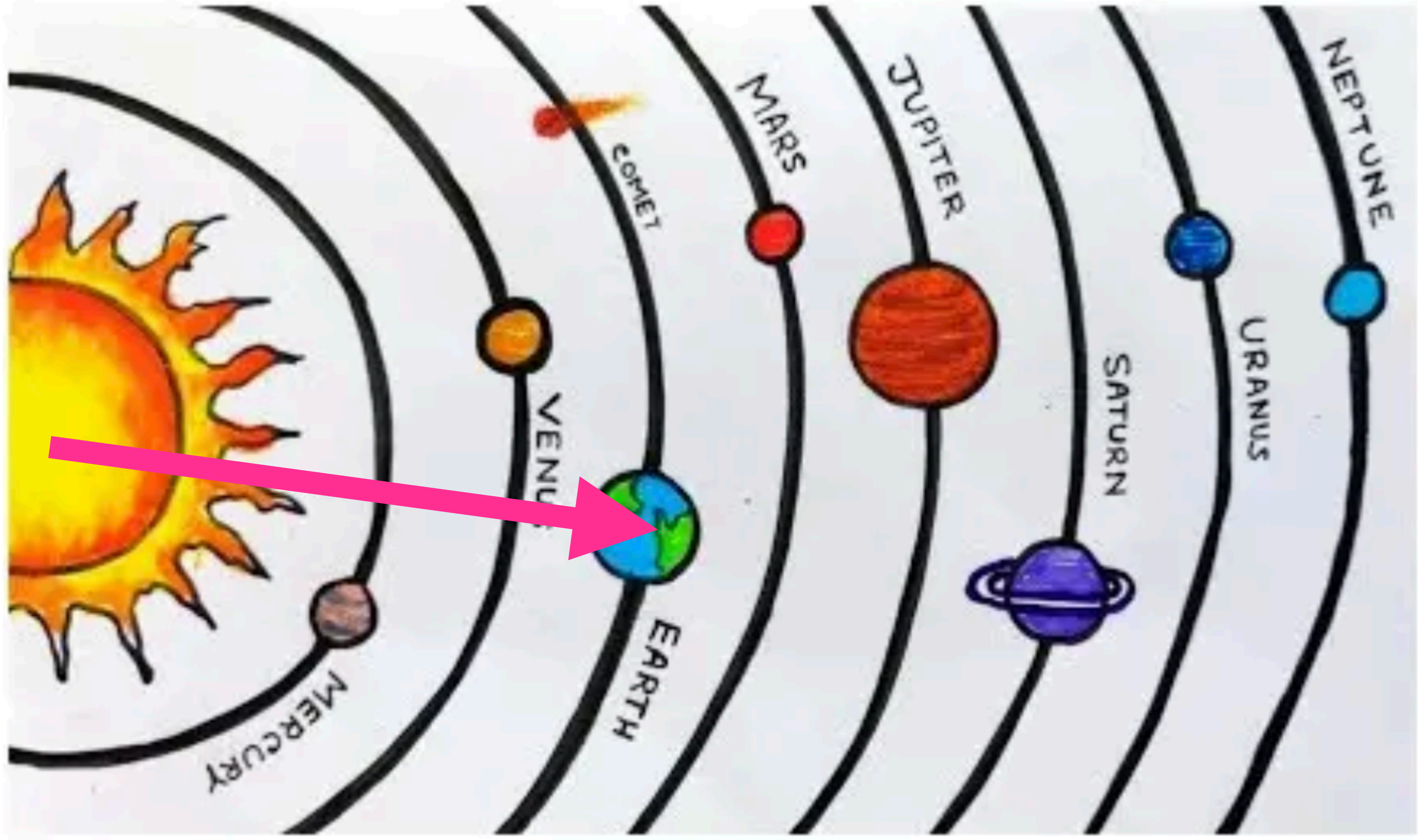
MRI

GPS

Newton's laws of classical mechanics

Summary of classical mechanics

$\vec{r}_3 = (x_3, y_3, z_3)$



$$\Big(\vec{r}(t=0), \dot{\vec{r}}(t=0)\Big) \to \Big(\vec{r}(t), \dot{\vec{r}}(t)\Big)$$

Initial conditions define evolution in the future AND in the past

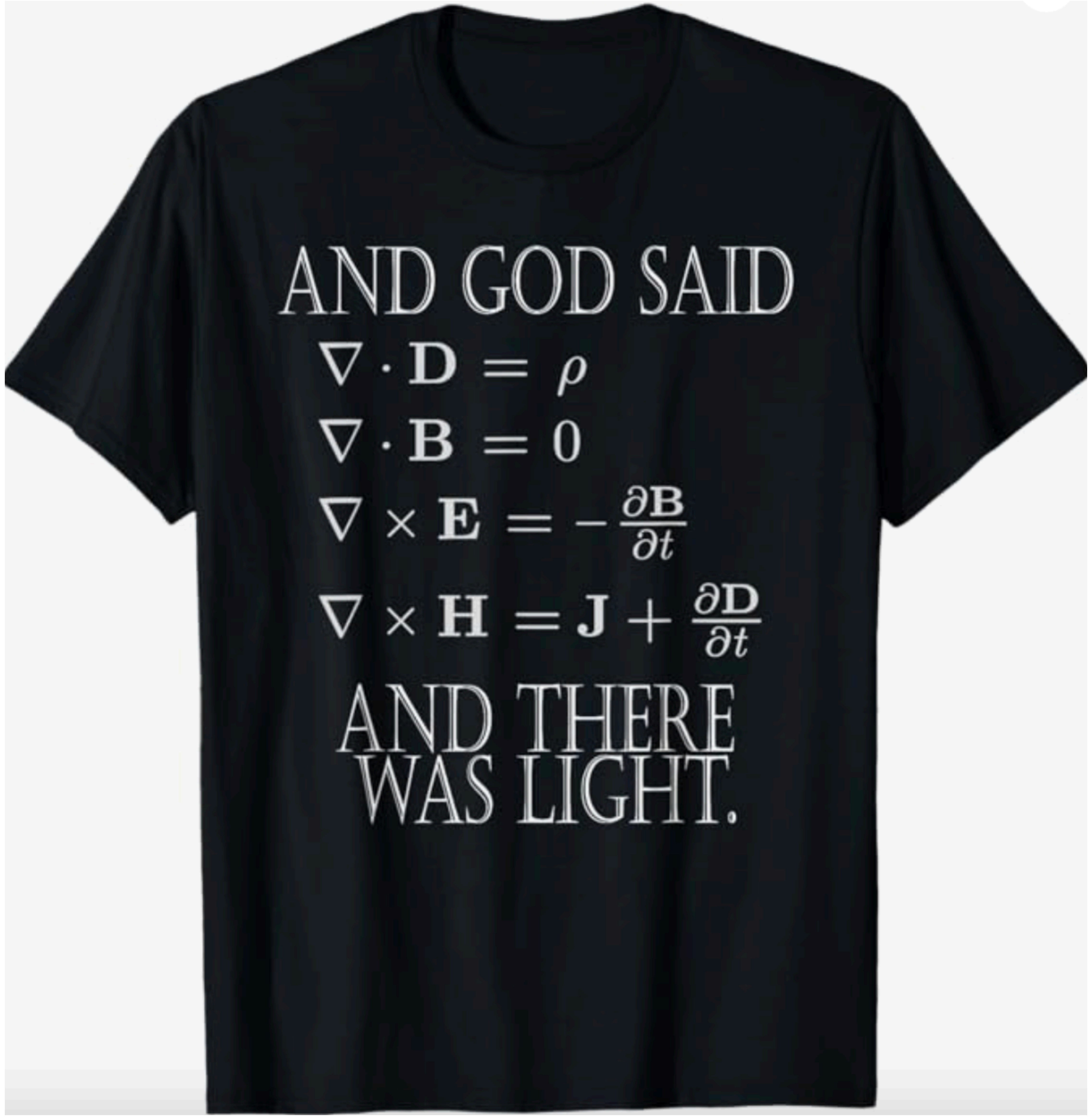
Example: N-body motion under gravity force

$$\left[\begin{aligned}
m_i \frac{dv_{ix}}{dt} &= \sum_{j=1}^{N} -\frac{G m_i m_j (x_i - x_j)}{r_{ij}^3}, \\
m_i \frac{dv_{iy}}{dt} &= \sum_{j=1}^{N} -\frac{G m_i m_j (y_i - y_j)}{r_{ij}^3}, \\
m_i \frac{dv_{iz}}{dt} &= \sum_{j=1}^{N} -\frac{G m_i m_j (z_i - z_j)}{r_{ij}^3}. \\
v_{ix} &= \frac{dx_i}{dt} \\
v_{iy} &= \frac{dy_i}{dt} \\
v_{iz} &= \frac{dz_i}{dt}
\end{aligned}\right.$$

6N non-linear first-order differential equations

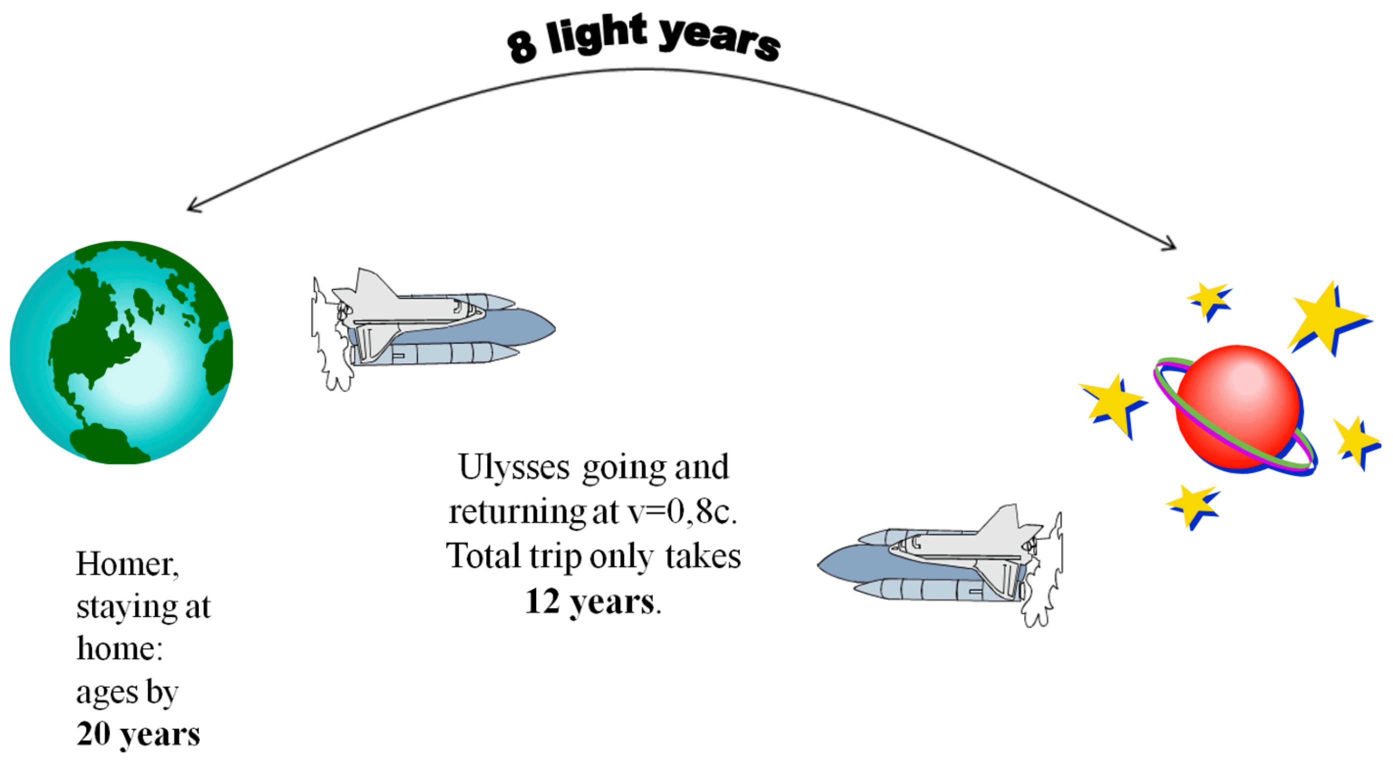
$$r_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2 + (z_i - z_j)^2}.$$

Summary of electromagnetism



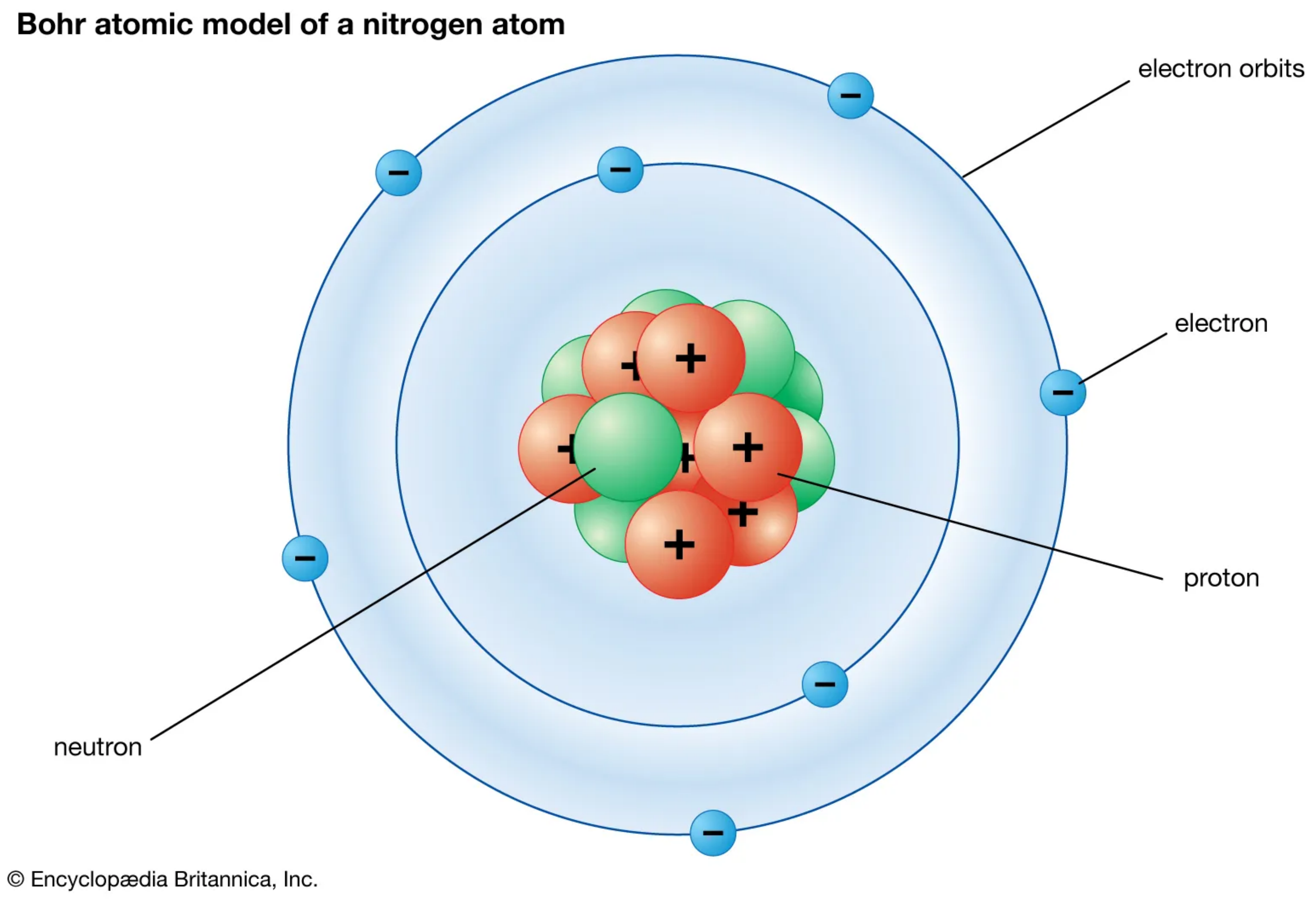
Similar to mechanics,
but now particles have charge,
charge interacts with E & B fields.

+ a bit of relativity magic



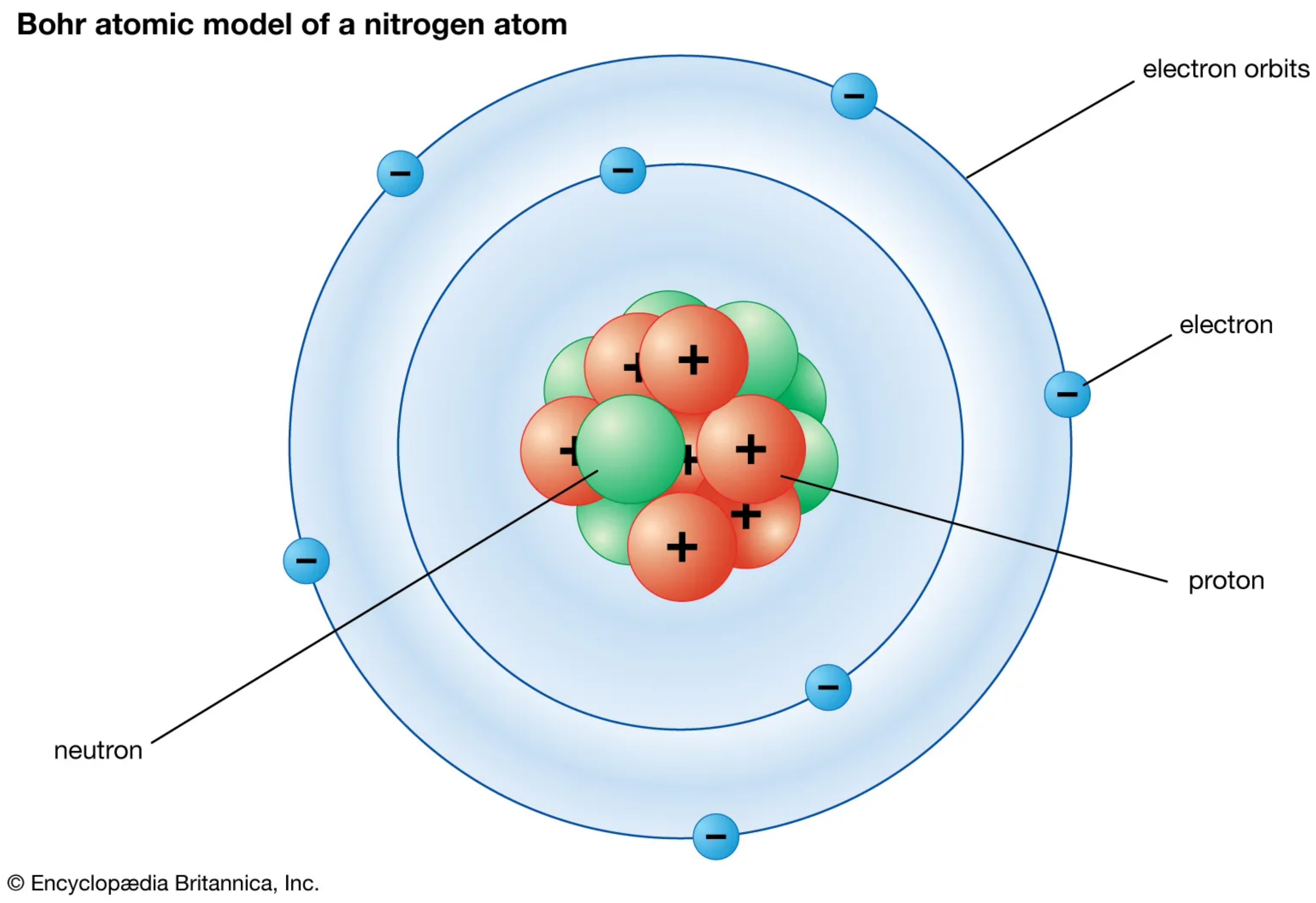
Rules are different in the **microworld**

“-” electrons spin around “+” nucleus



Atoms are classically unstable

"-" electrons spin around "+" nucleus



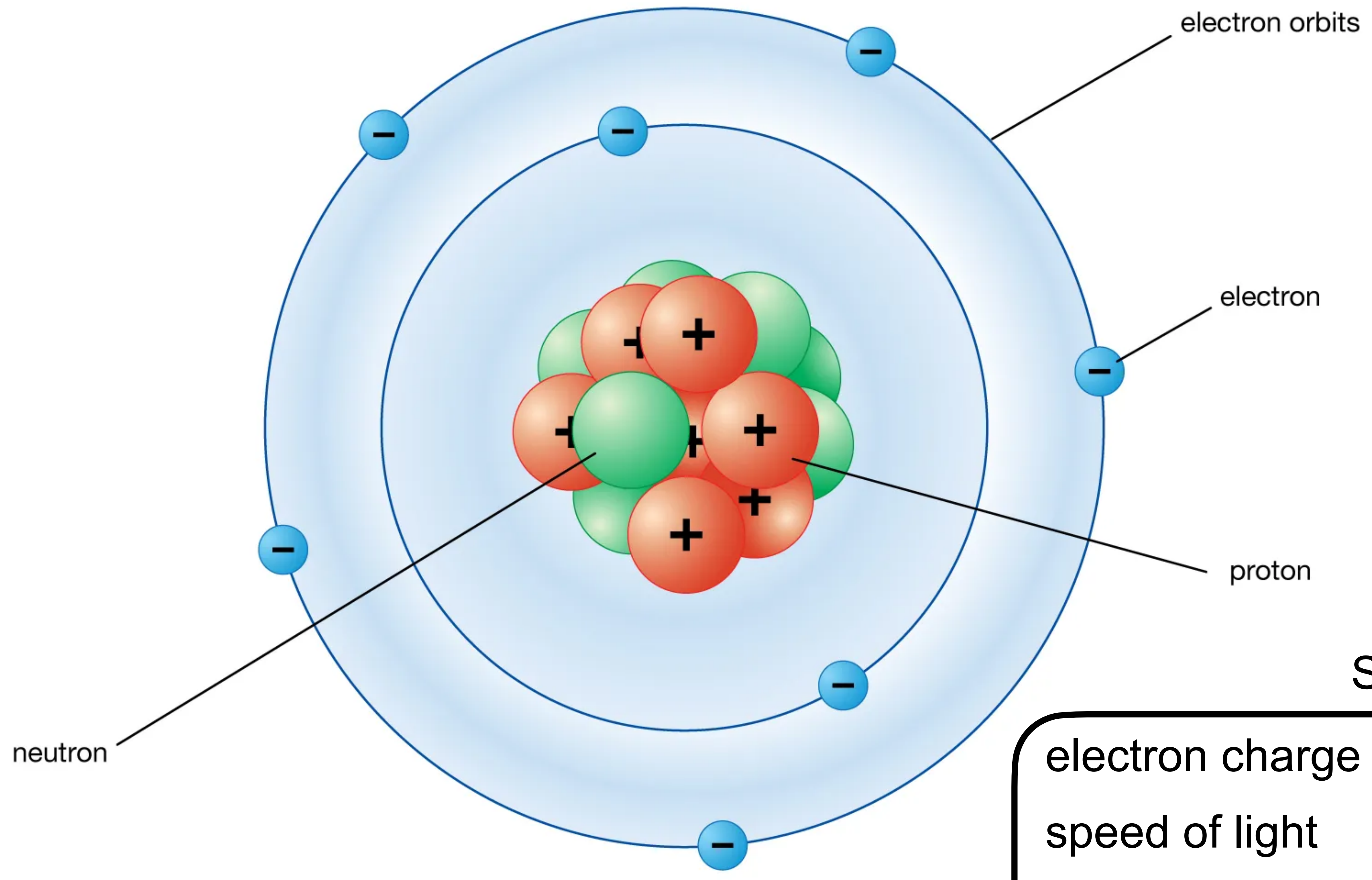
Accelerated charges radiate EM waves

Classically, electron will loose most of its energy and fall onto the nucleus in about **10^{-11}** seconds

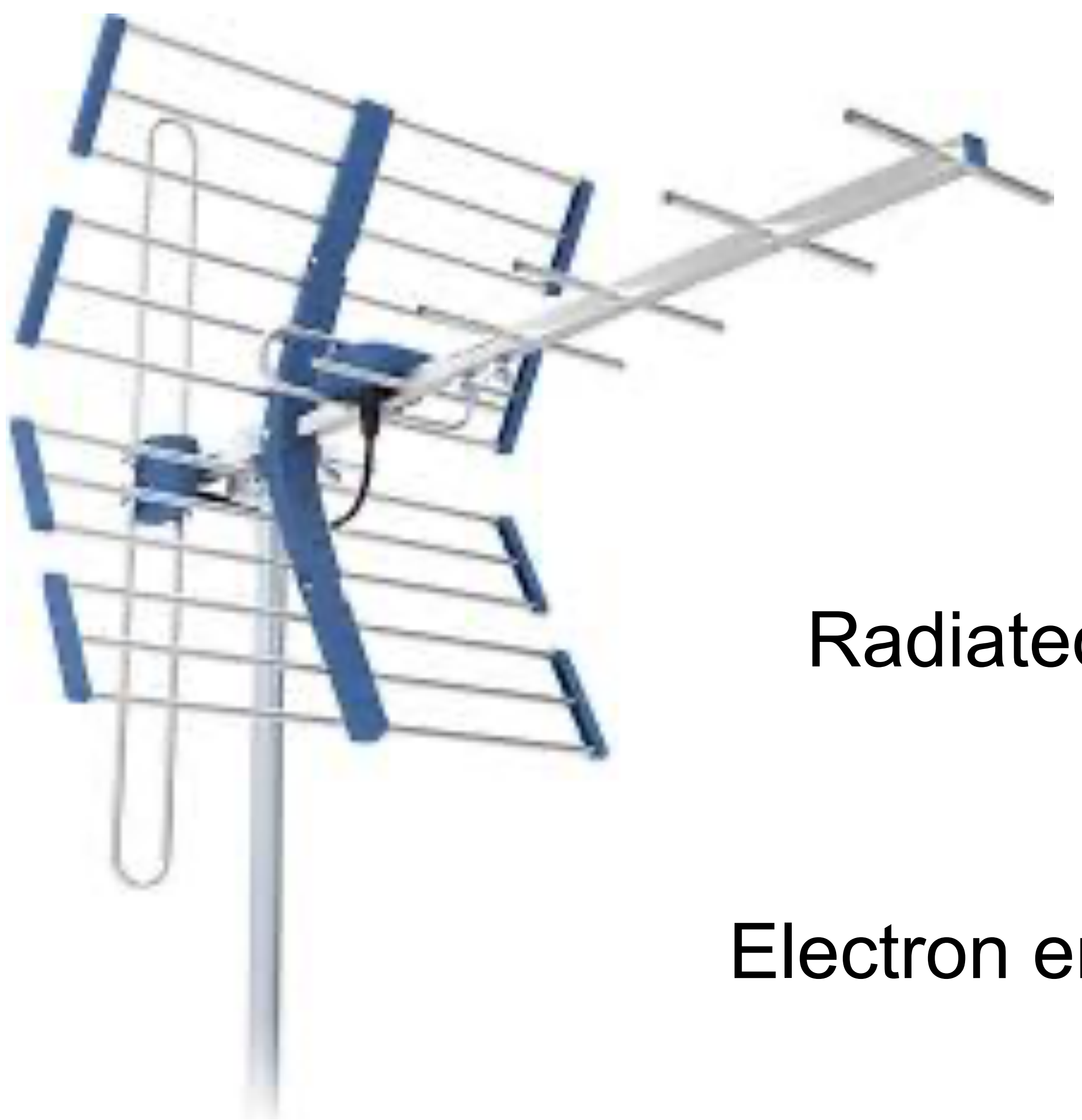
Quantum mechanics makes matter possible

Atoms are classically impossible: version for nerds only

“-” electrons spin around “+” nucleus



Accelerated charges radiate EM waves



acceleration

Radiated power $P = \dfrac{e^2(\omega^2 x_0)^2}{12\pi\epsilon_0 c^3}$

Electron energy $E = m(\omega x_0)^2/2$

Electron acceleration $m\omega^2 x_0 = \dfrac{e^2}{4\pi\epsilon_0 x_0^2}$

S.I. units

electron charge	$e \approx 1.6 \times 10^{-19}$
speed of light	$c \approx 3 \times 10^{8}$
vacuum permittivity	$\epsilon_0 \approx 10^{-11}$
electron mass	$m \approx 10^{-30}$
typical size of atoms	$x_0 \approx 10^{-10}$

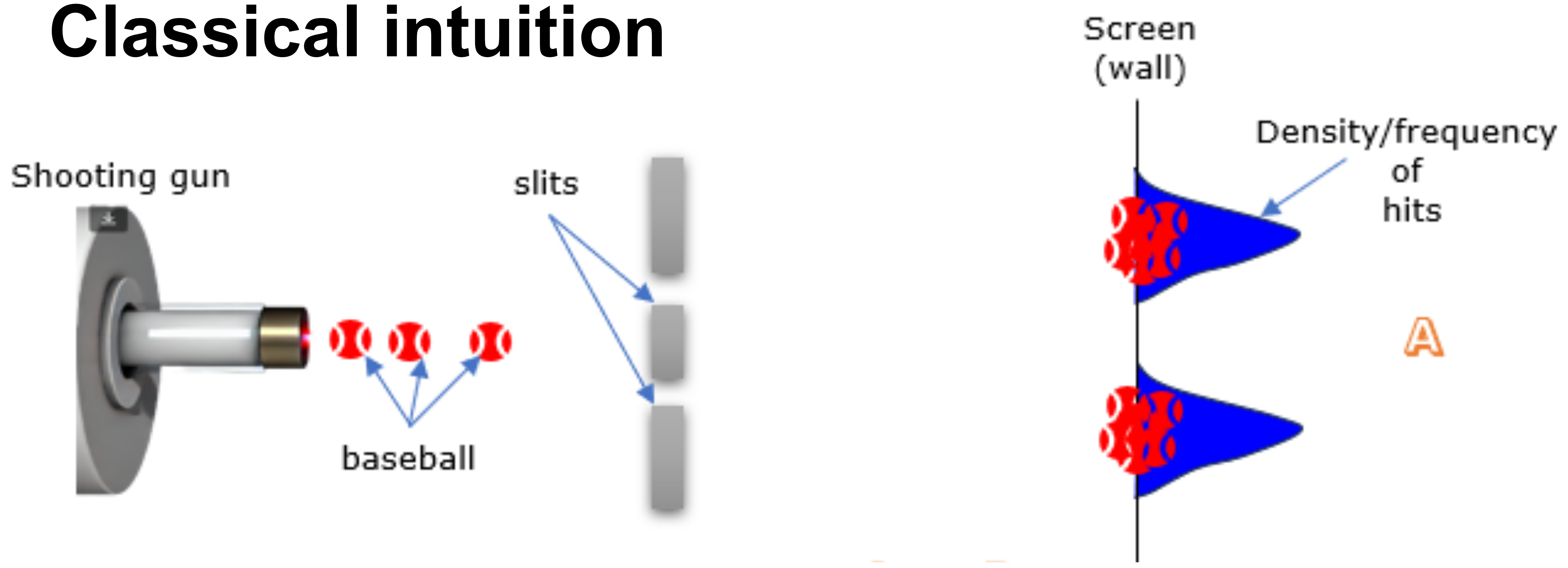
$$t \approx |E|/P \approx (4\pi\epsilon_0)^2 m^2 x_0^3 c^3 / e^4$$

$$t \approx 10^{-11} \text{ sec}$$

atom collapse time scale

Particle-wave duality

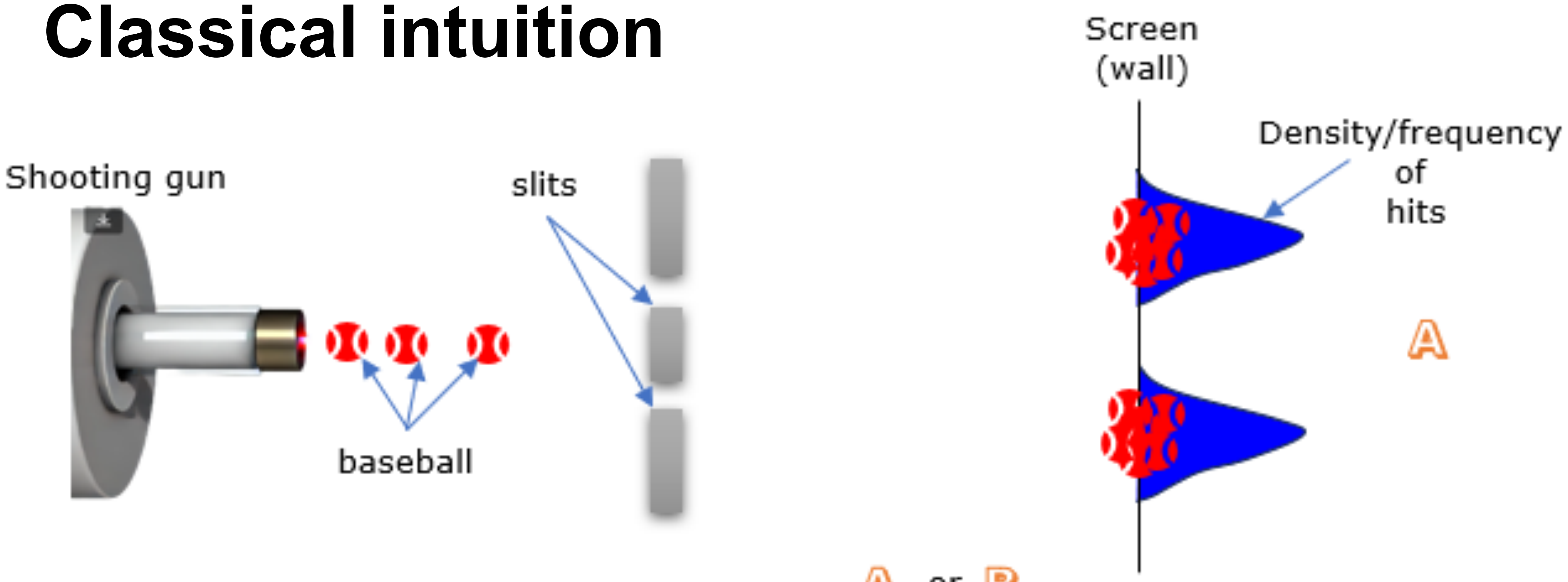
Classical intuition



Same energy for each particle

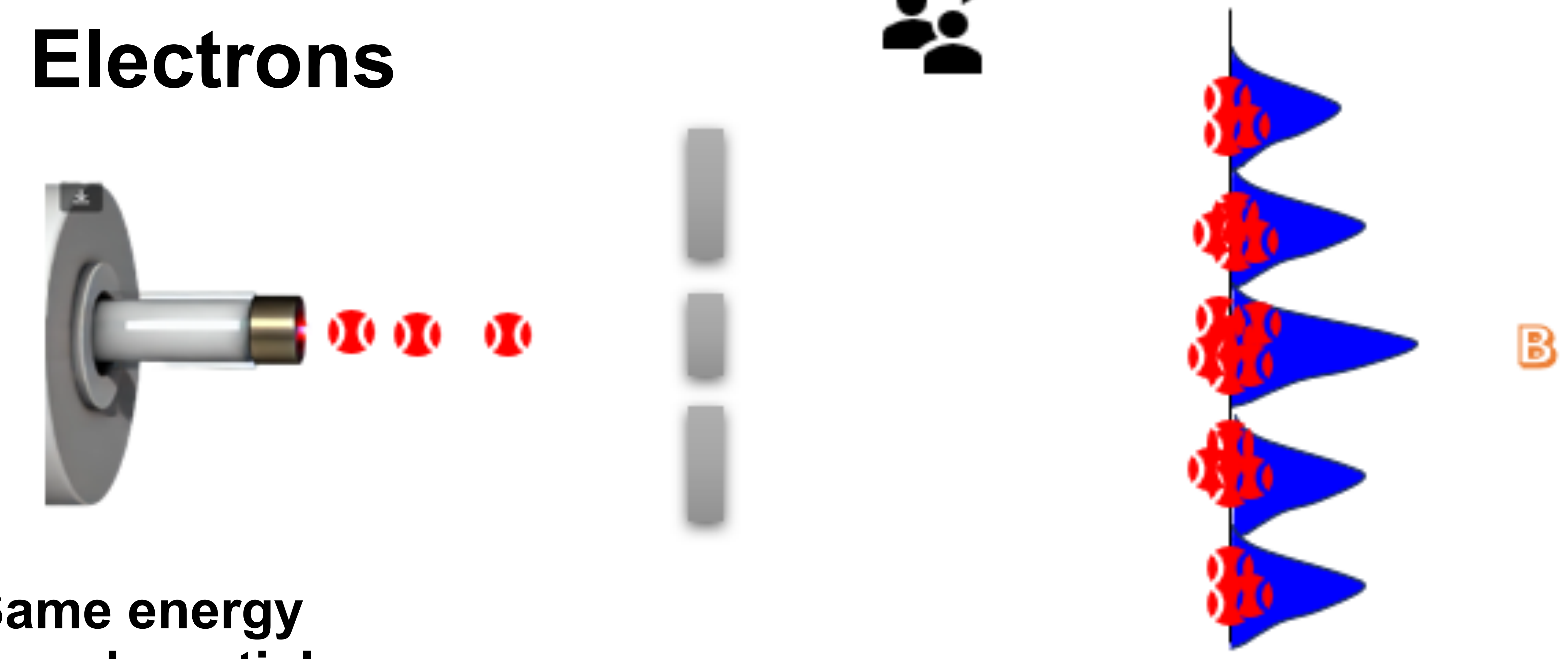
Particle-wave duality

Classical intuition



OR

Electrons



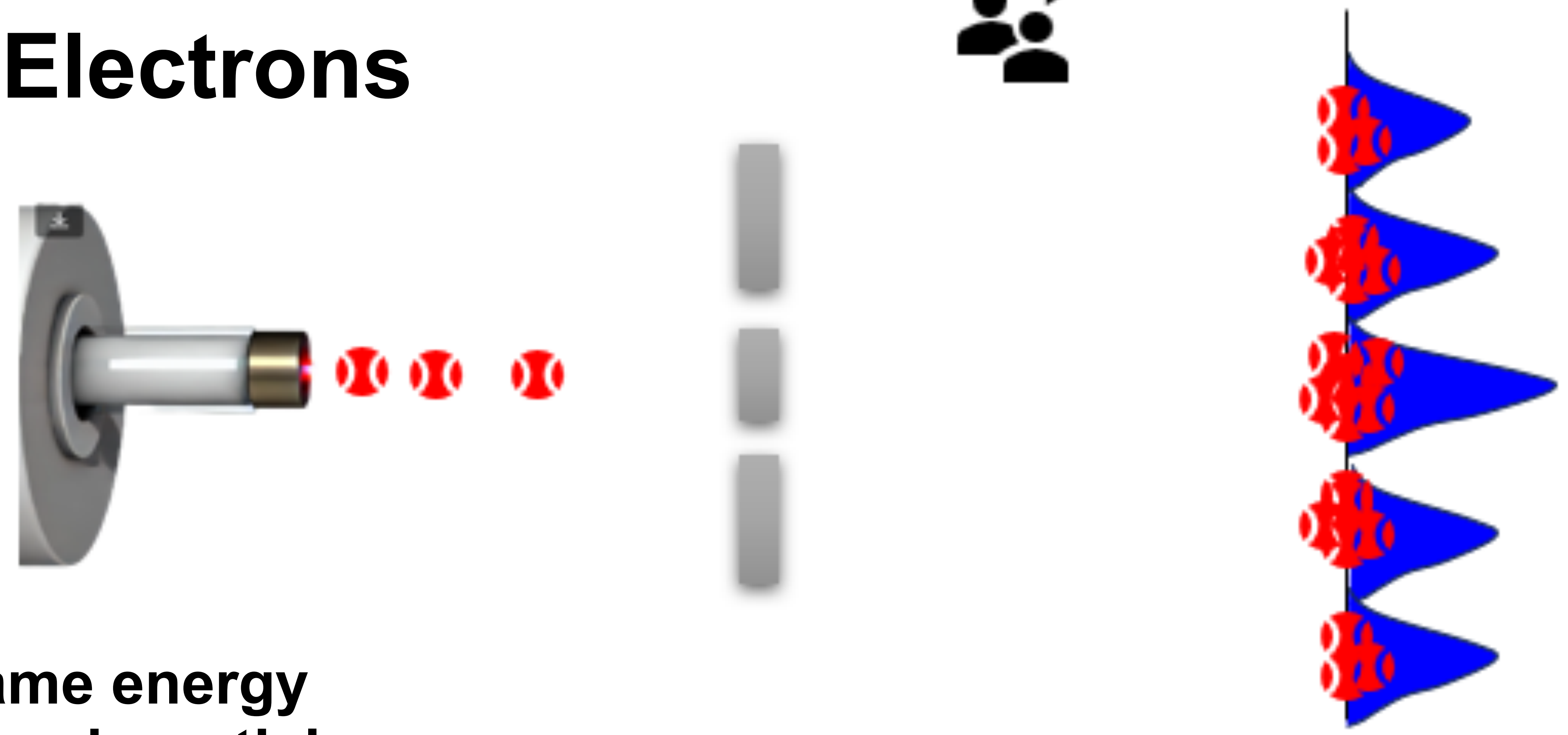
Same energy for each particle

Two options to get somewhere **interfere** constructively or destructively!

Classical intuition

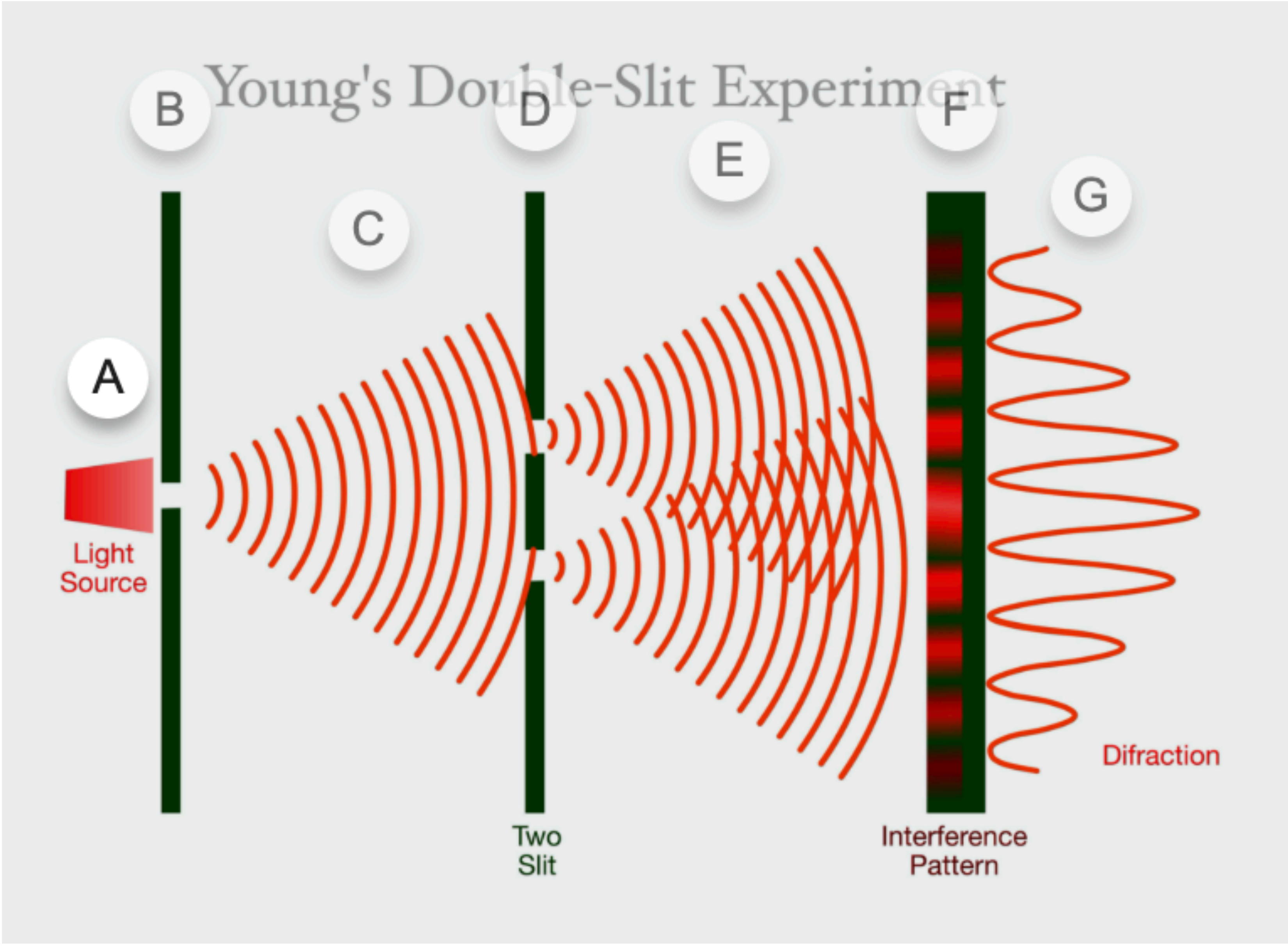
OR

Electrons

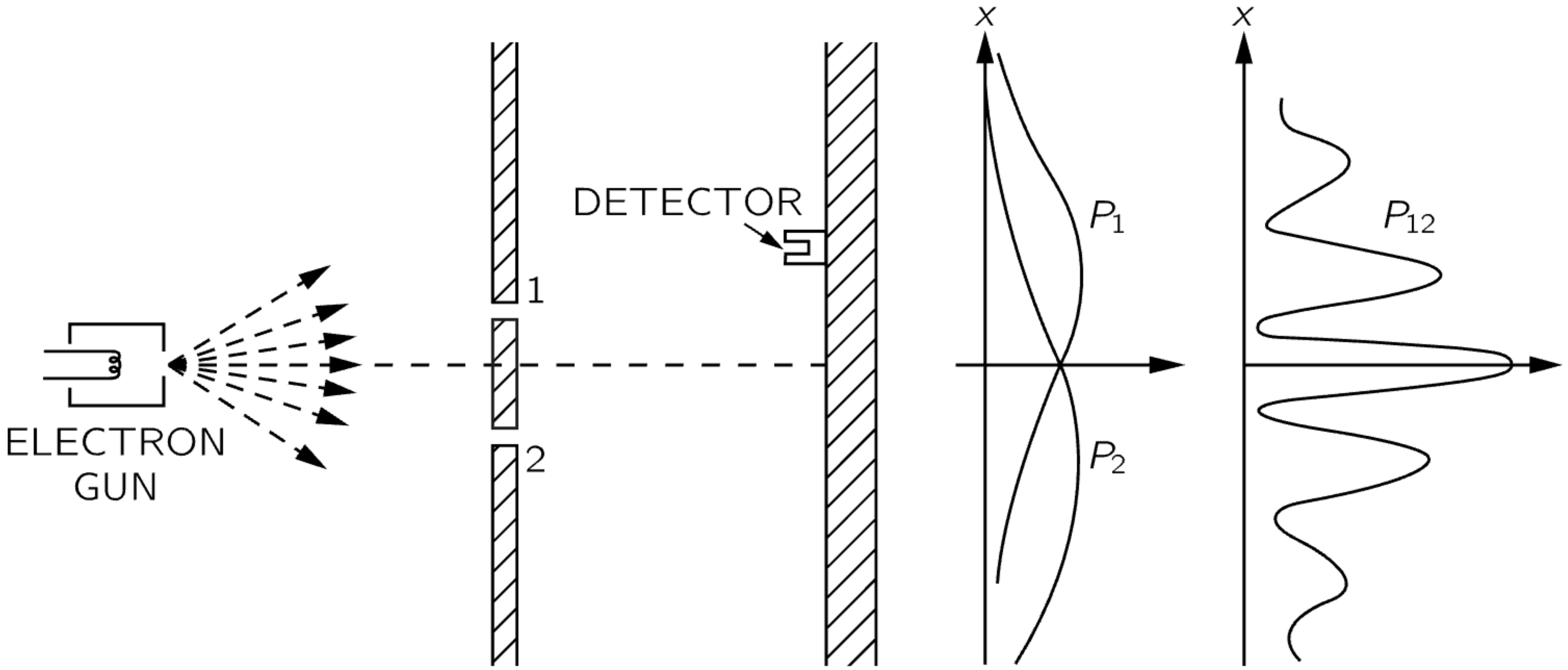


Same energy for each particle

light/sound waves behave like that

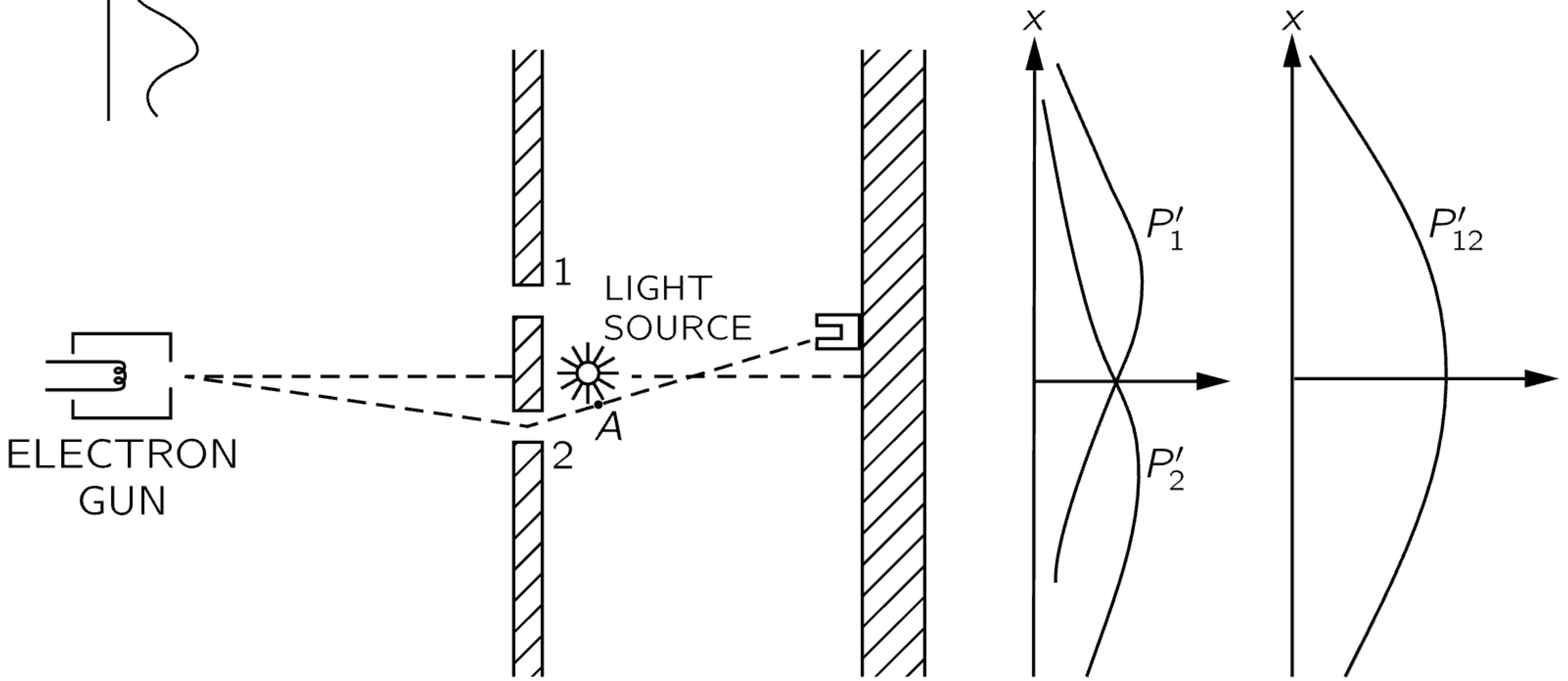


Measurement always **perturbs** the system in the microworld



Electron passed through slit 1 —> False
Electron passed through slit 2 —> False

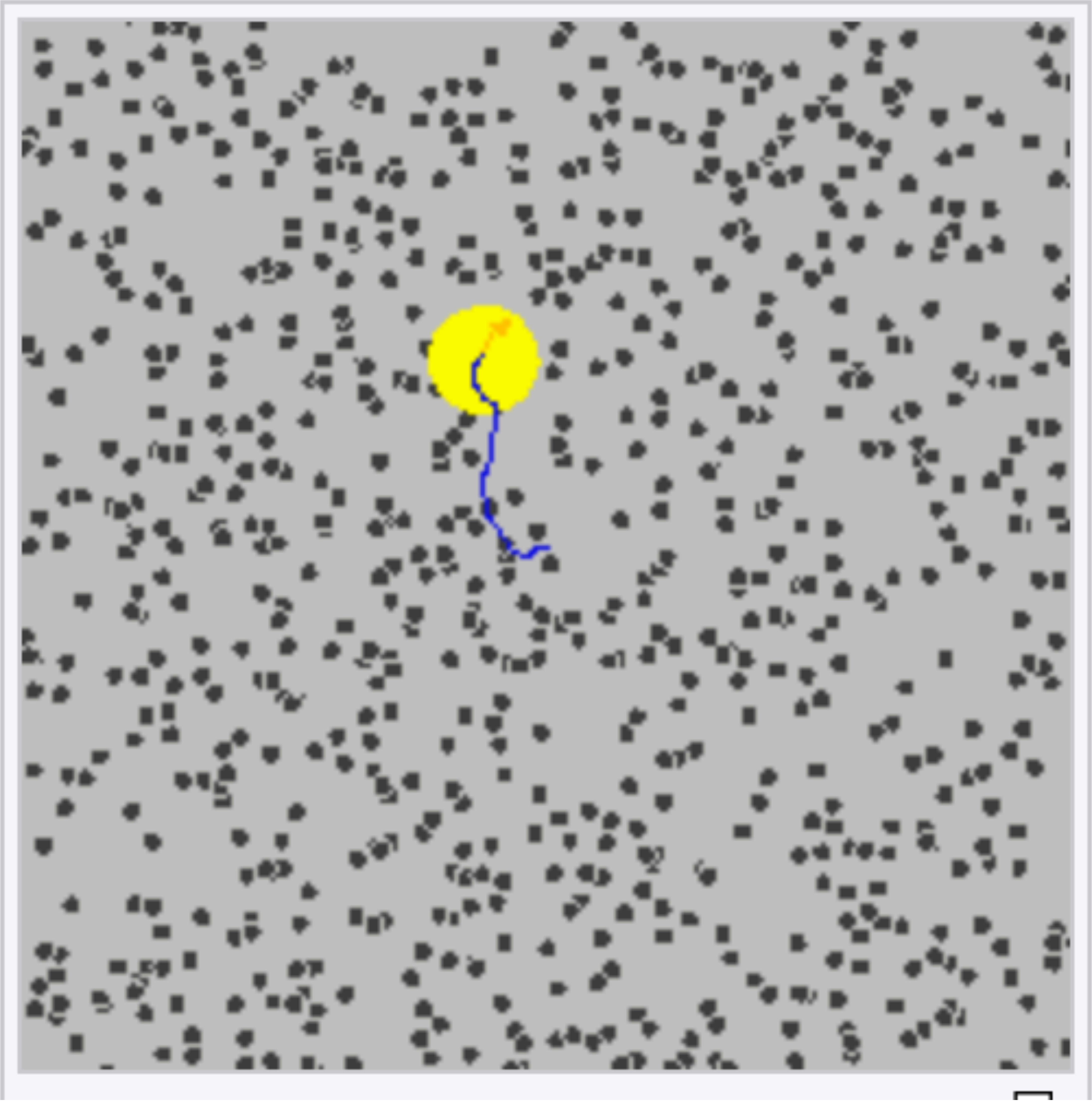
Try to see which path electron took
—> no interference



$P'_{12} = P'_1 + P'_2$

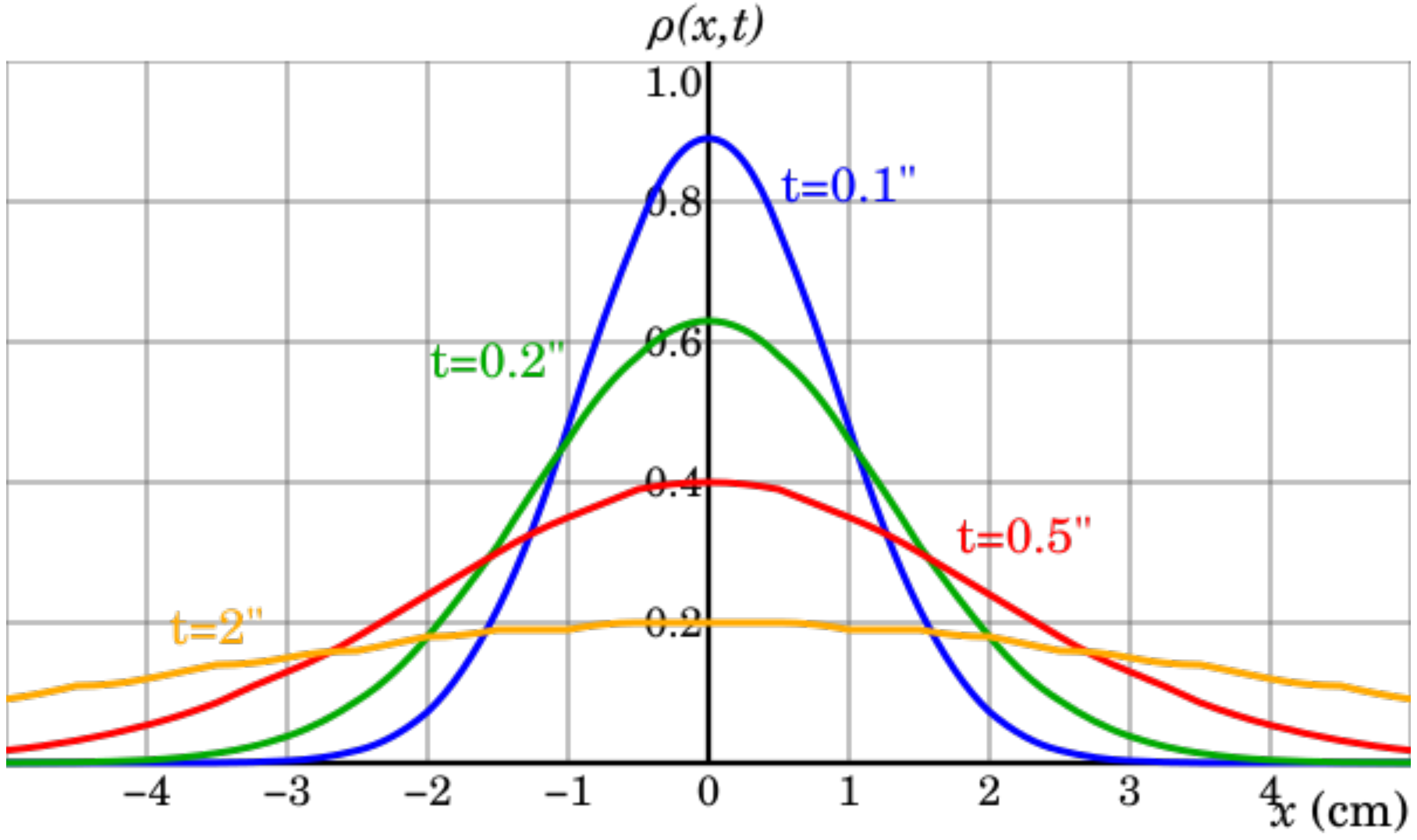
In order to see where electron is, the scattered light must alter electron’s future

Classical **randomness** is pure **ignorance**.
Quantum randomness is real!



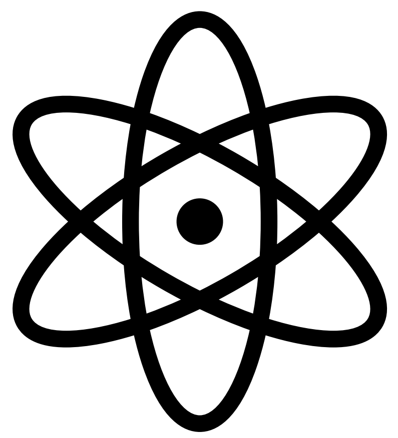
Classical particle appears moving randomly because we can't keep track of every other particle around it

Quantum particle honestly can't know…

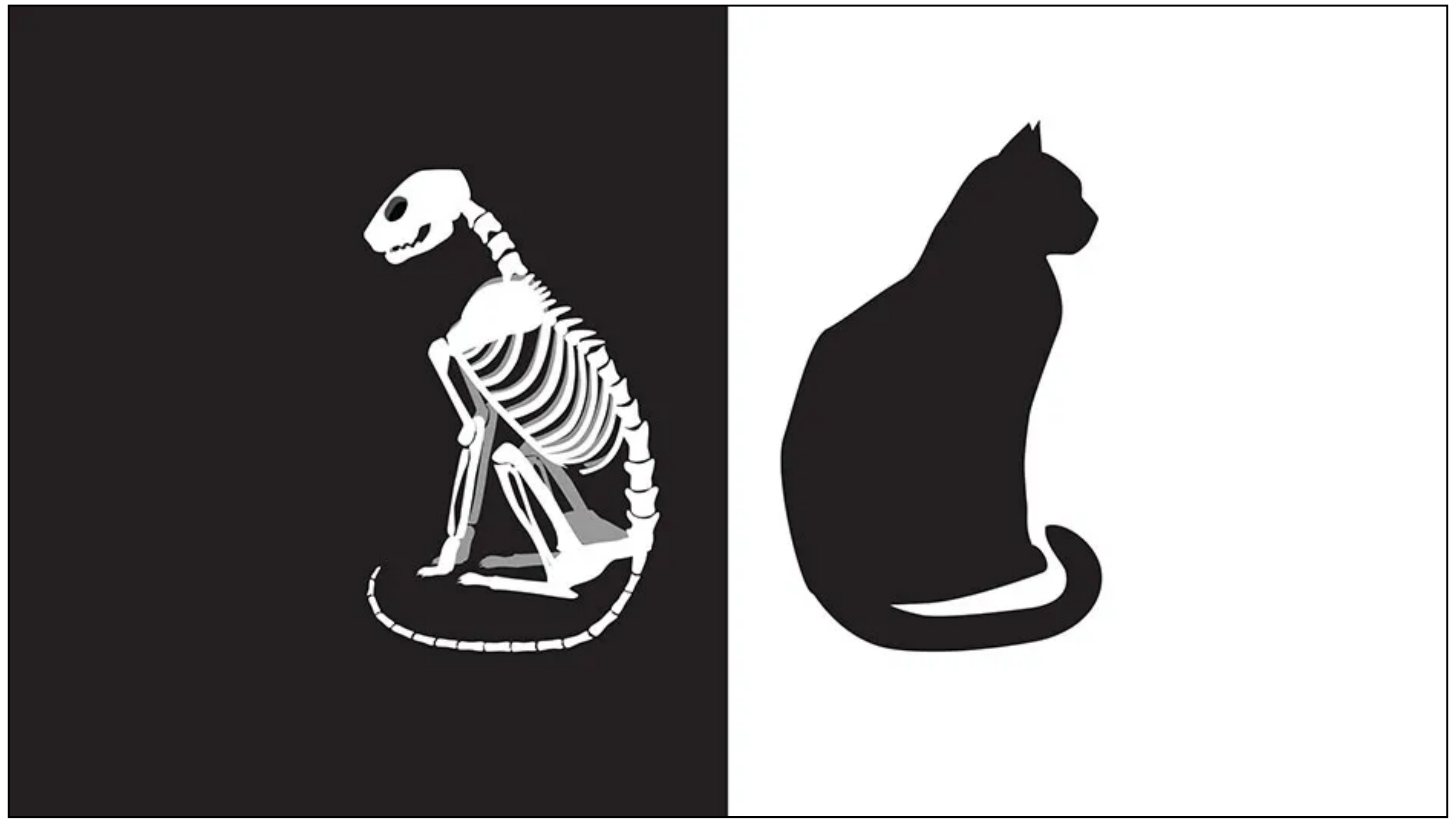


Quantum **2.0**

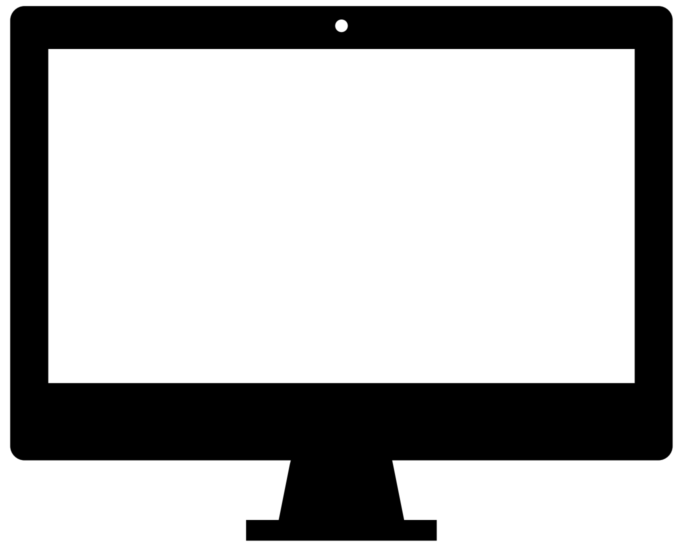
Atom



Schrodinger's Cat



A more **efficient** way to process information?



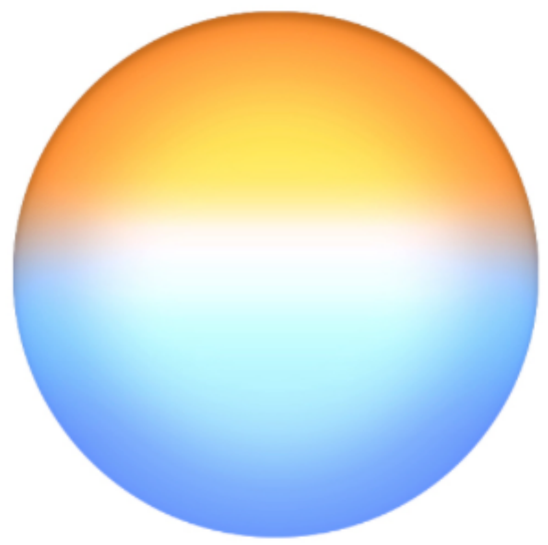
Bit
(Classical Computing)

0

1

Qubit
(Quantum Computing)

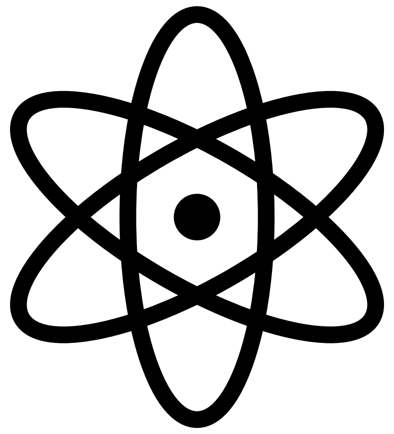
0



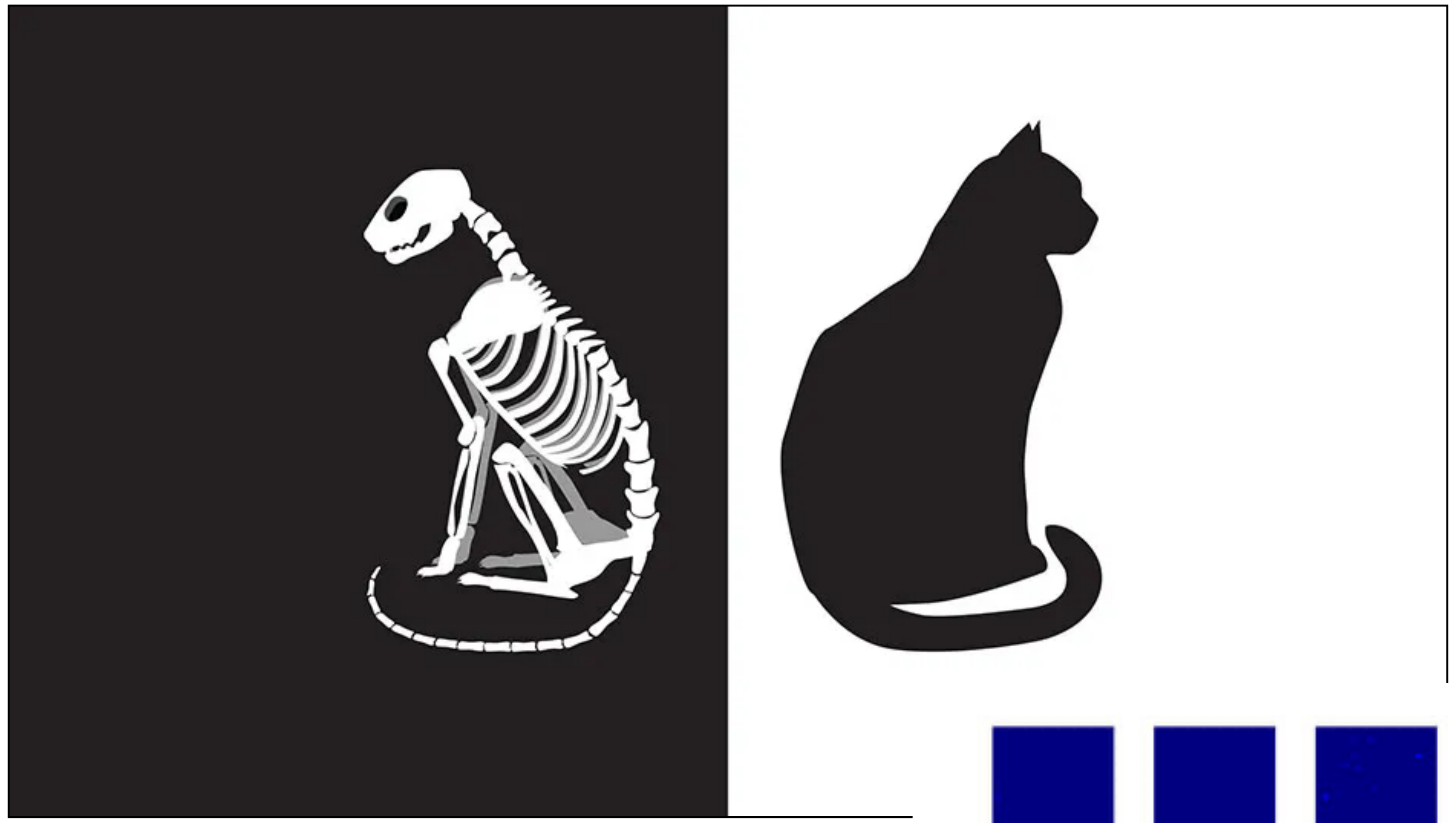
1

Quantum **2.0**

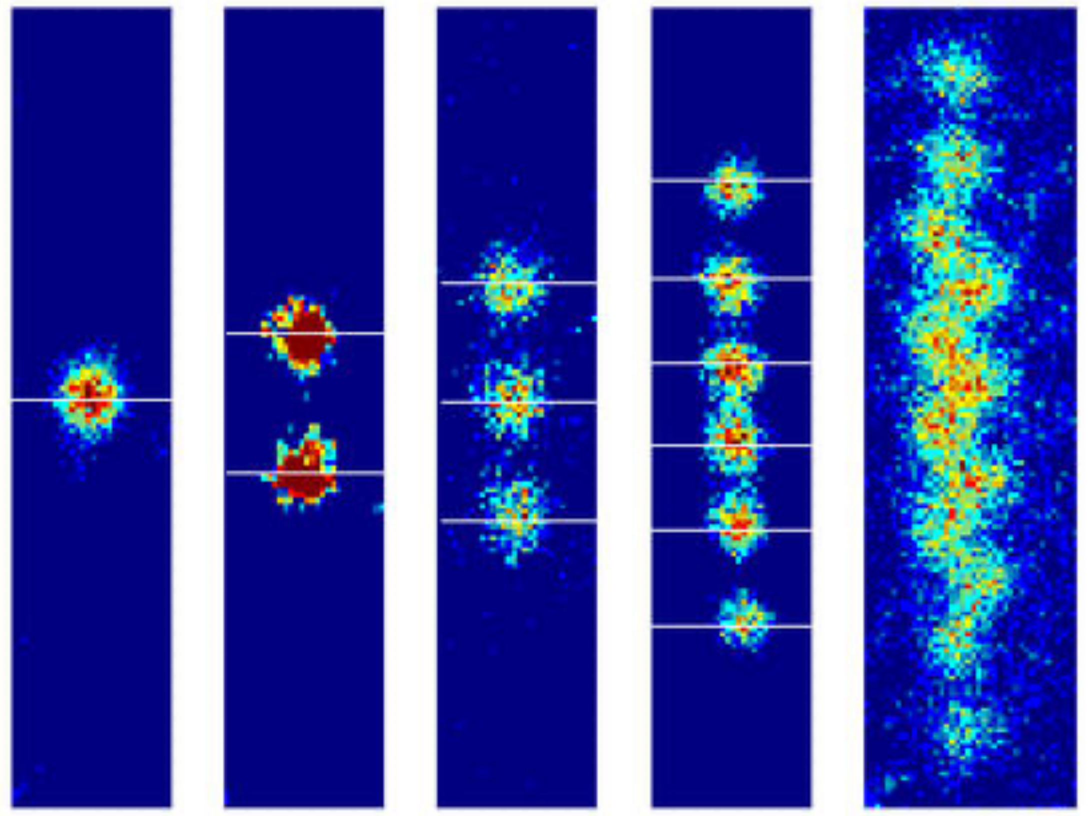
Atom



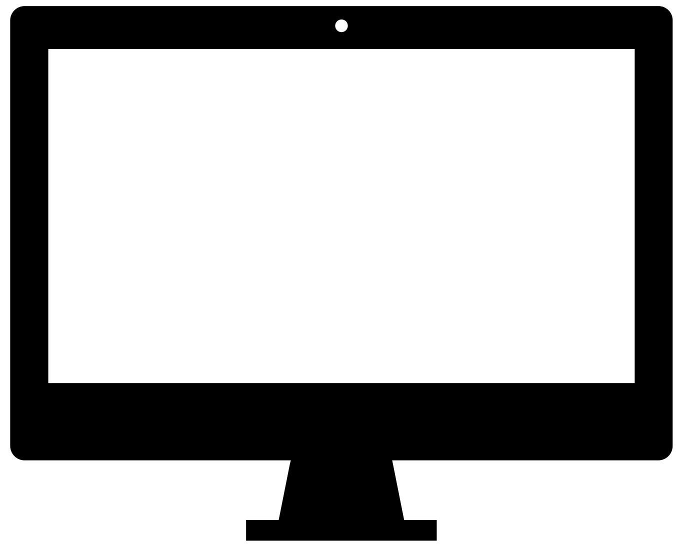
Schrodinger's Cat

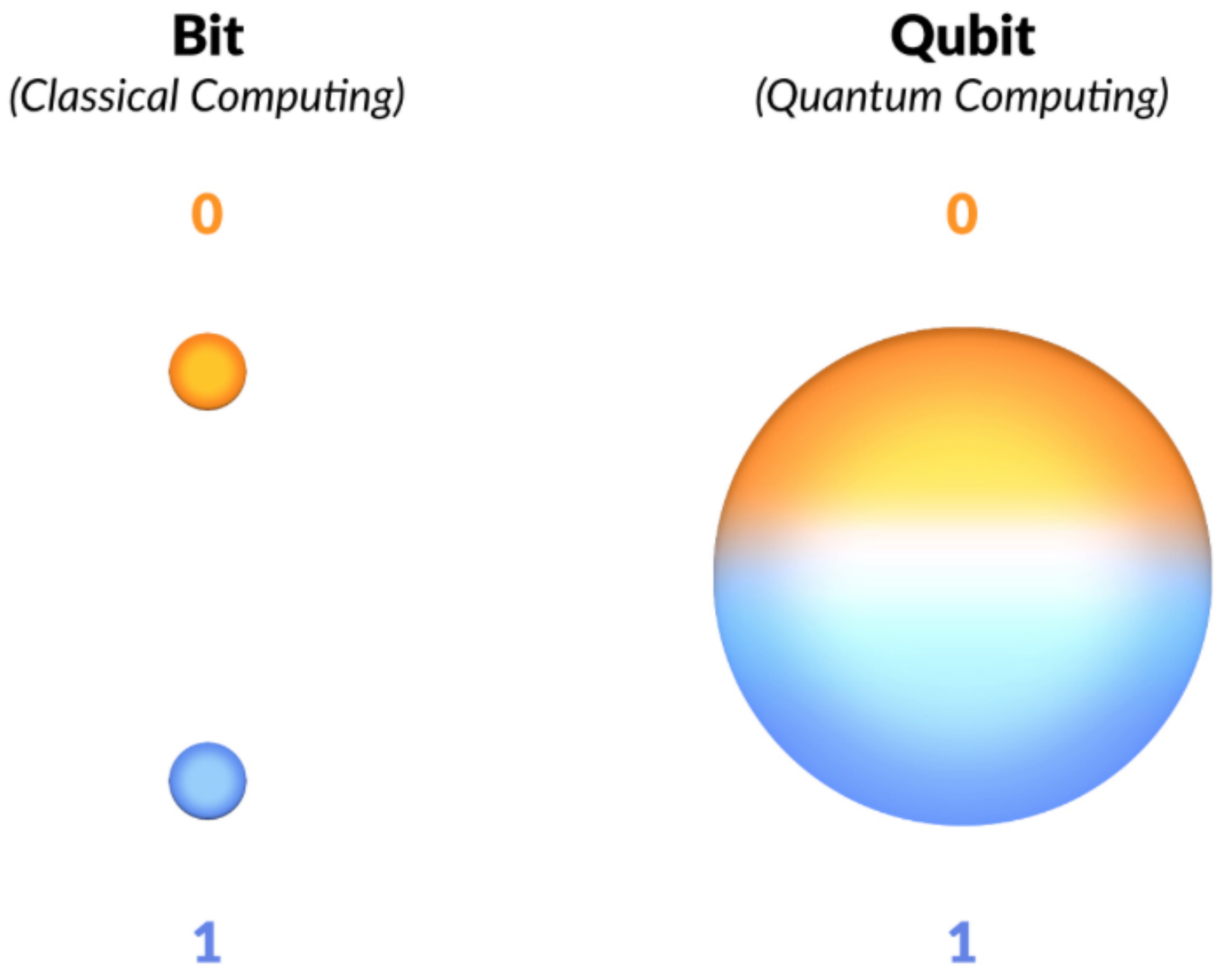


Trapping and seeing (in a microscope) 1, 2, 3, 6, and 12 **individual** magnesium ions



A more **efficient** way to process information?





McKinsey & Company

Quantum computing

$45B–$131B
estimated market size by 2040

$6.7B
invested
as of Dec 2023

261
start-ups
as of Dec 2023

$173B

potential quantum technology market size by 2040[1]

367
start-ups in the ecosystem[2]

~$42B total government investment announced

Quantum communication

$24B–$36B
estimated market size by 2040

$1.2B
invested
as of Dec 2023

96
start-ups
as of Dec 2023

Quantum sensing

$1B–$6B
estimated market size by 2040

$0.7B
invested
as of Dec 2023

48
start-ups
as of Dec 2023

Potential economic value from quantum computing

~$0.9T–$2T
across four industries by 2035: chemicals, life sciences, finance, and mobility[3]

Quantum-capable talent

55
QT master's degree programs

195
universities with QT research groups

Scientific progress

4,763
QT-related patents granted in 2022

42,155
QT-related publications in 2023

McKinsey & Company

Quantum computing

$45B–$131B
estimated market size by 2040

$6.7B
invested
as of Dec 2023

261
start-ups
as of Dec 2023

$173B
potential quantum
market size by

367
start-ups in the ec

~$42B total
inve

Quantum communication

$24B–$36B
estimated market size by 2040

$1.2B
ested
2023

96
start-ups
as of Dec 2023

antum sensing

$1B–$6B
ated market size by 2040

7B
ested
2023

48
start-ups
as of Dec 2023

Potential economic value from quantum computing

~$0.9T–$2T
across four industries by 2035: chemicals, life sciences, finance, and mobility[3]

Quantum-capable talent

55
QT master's degree programs

195
universities with QT research groups

Scientific progress

4,763
QT-related patents granted in 2022

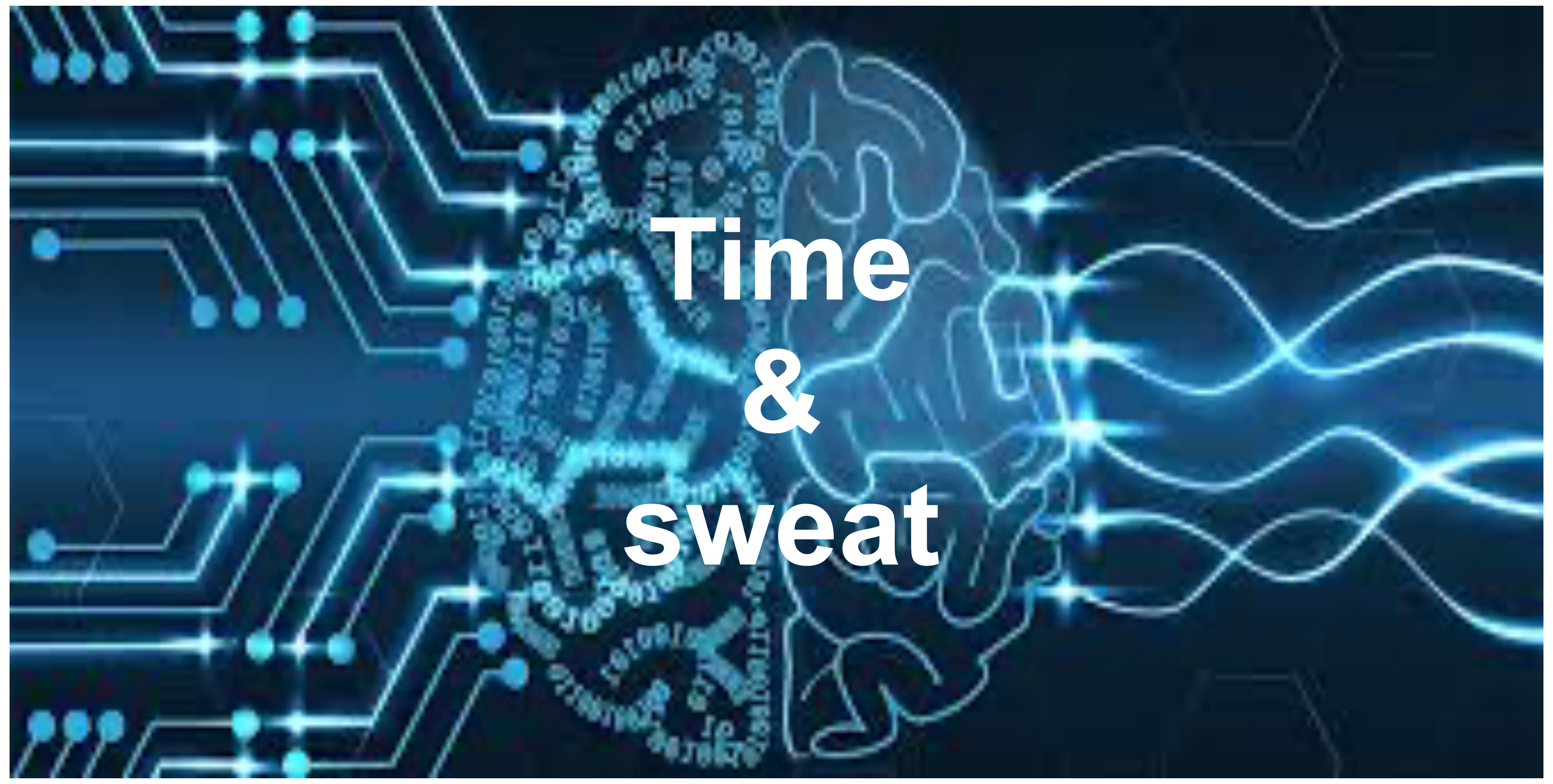
42,155
QT-related publications in 2023

PHYS-344: **QUANTUM** MECHANICS FOR **NON-PHYSICISTS**

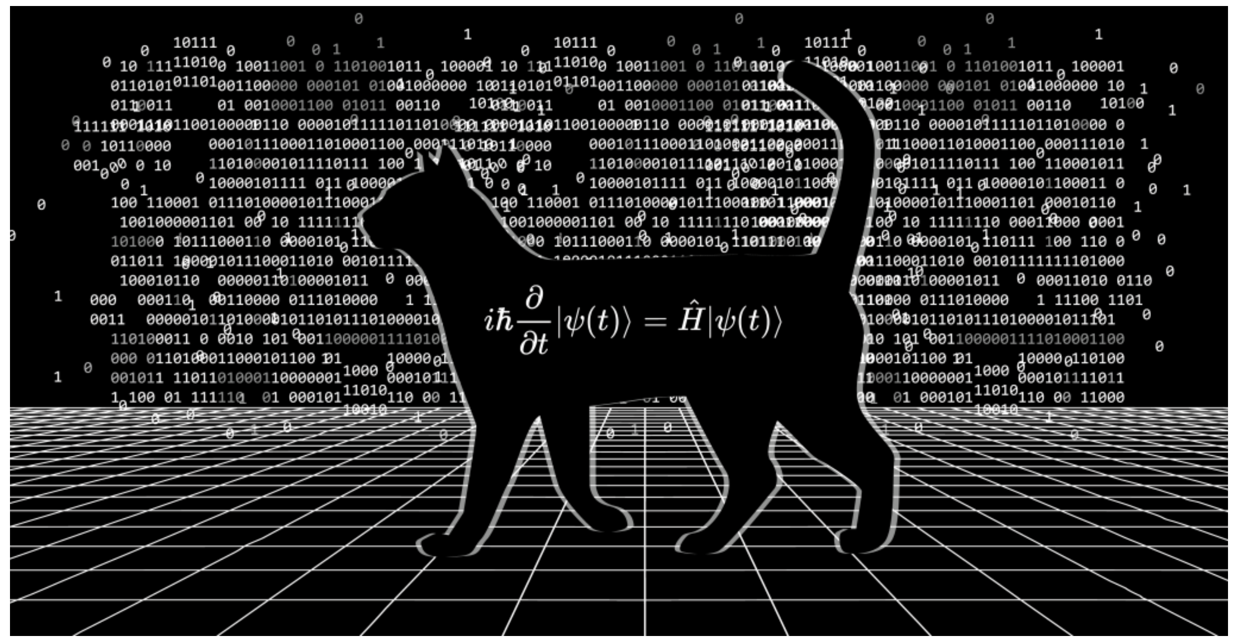
Syllabus

1. Intro (HW0)
2. Mathematics of quantum bits (HW1)
3. Quantum harmonic oscillator (HW2)
4. Basic quantum systems (HW2)
5. Two-qubit systems and entanglement (HW3)
6. Special topics: cavity QED/decoherence/quantum measurement (HW4)

Teaching philosophy



Quantum intuition



You are able to:

- ~~understand quantum mechanics~~
- ~~operate quantum computers safely~~
- pursue regular quantum courses
- engage in quantum projects

PHYS-344: **QUANTUM** MECHANICS FOR **NON-PHYSICISTS**

PHYS344 is NOT a course on

- Quantum computing
- Quantum information
- Quantum technology
- Quantum communication

PHYS-344: **QUANTUM** MECHANICS FOR **NON-PHYSICISTS**

Simple **scoring system**

A) 5 homework sets

- each exercise is graded 0 or 1
- many are Python-based
- about 1/2 are explained during lectures/seminars

Up to 50% of your final score

B) Oral exam - course project

- learn a new topic and teach it to your peers
- each student presents/Q&A
- project choice finalised by ~ Oct 15 (TBD)

Up to 50% of your final score

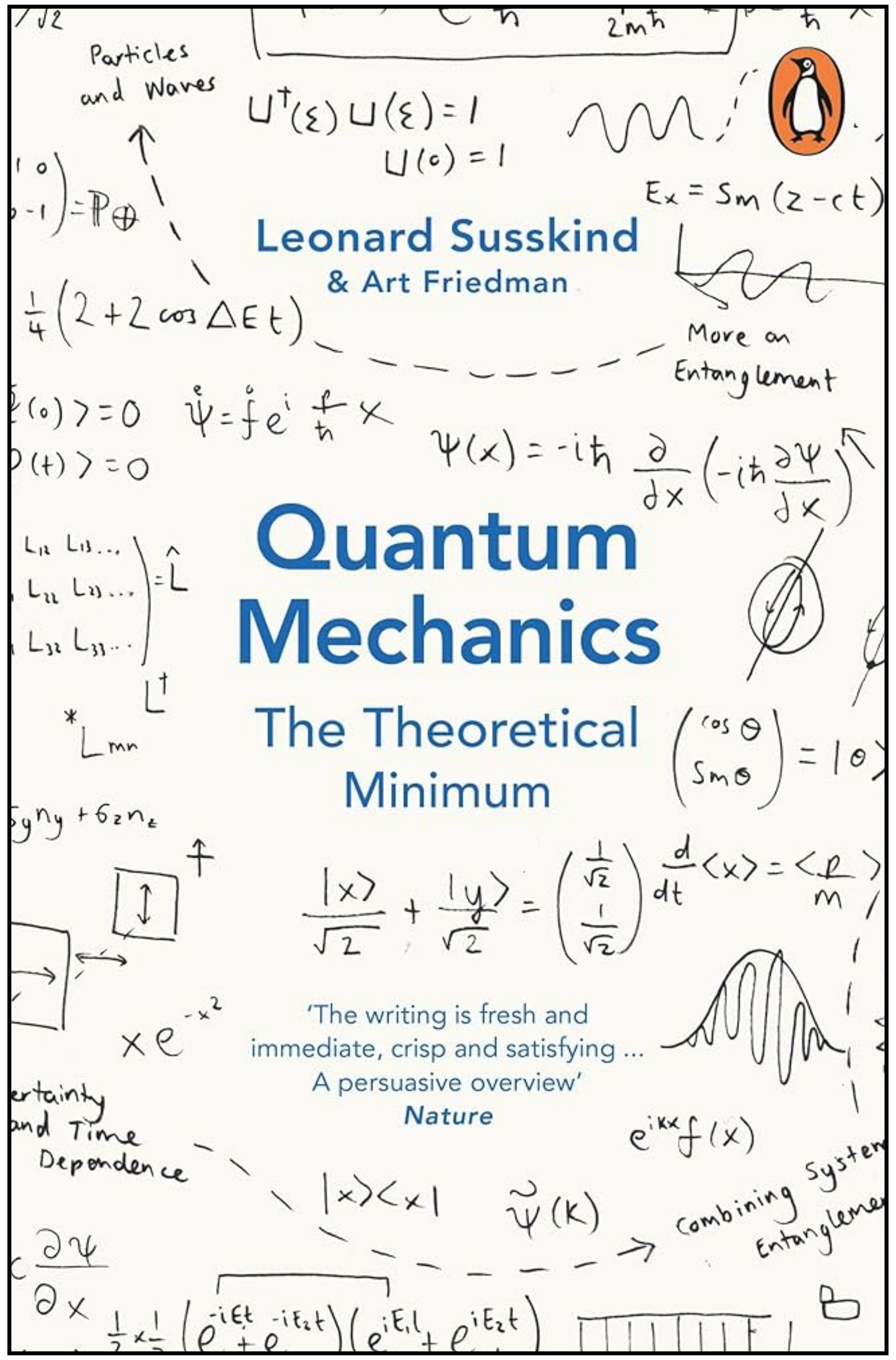
C) Extra credit opportunities

- report meaningful typos [use Forum]
- respond to questions of your peers [use Forum]

Up to +5% of your final score

PHYS-344: **QUANTUM** MECHANICS FOR **NON-PHYSICISTS**

Reading



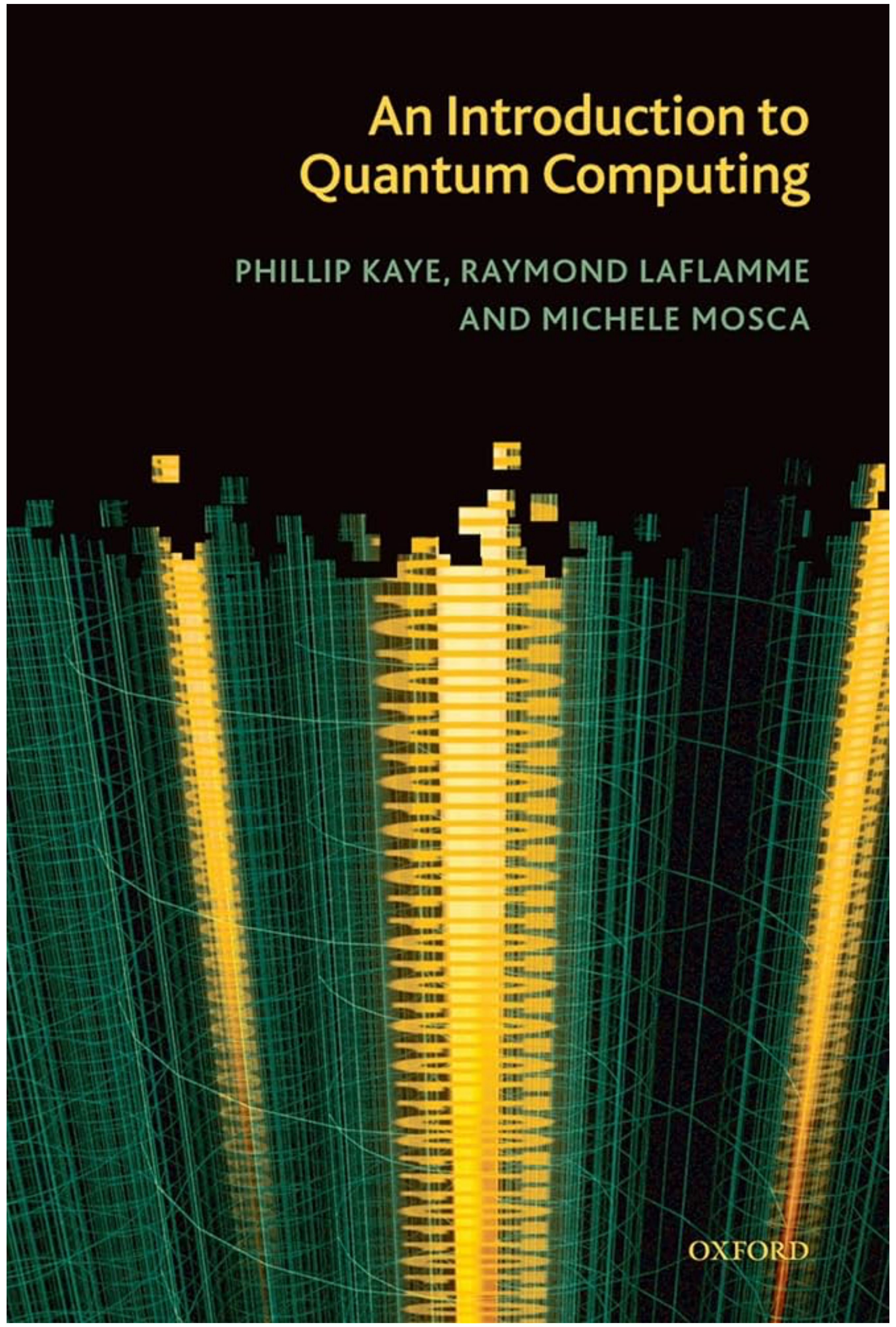
Slow modern intro for absolute beginners

comes with free video lectures
https://theoreticalminimum.com/courses/quantum-mechanics/2012/winter

Sold for 10-20 CHF

PHYS-344: **QUANTUM** MECHANICS FOR **NON-PHYSICISTS**

Reading



selected chapters

Concise intro of quantum formalism

2

BOOK

An introduction to quantum computing

Kaye, Phillip

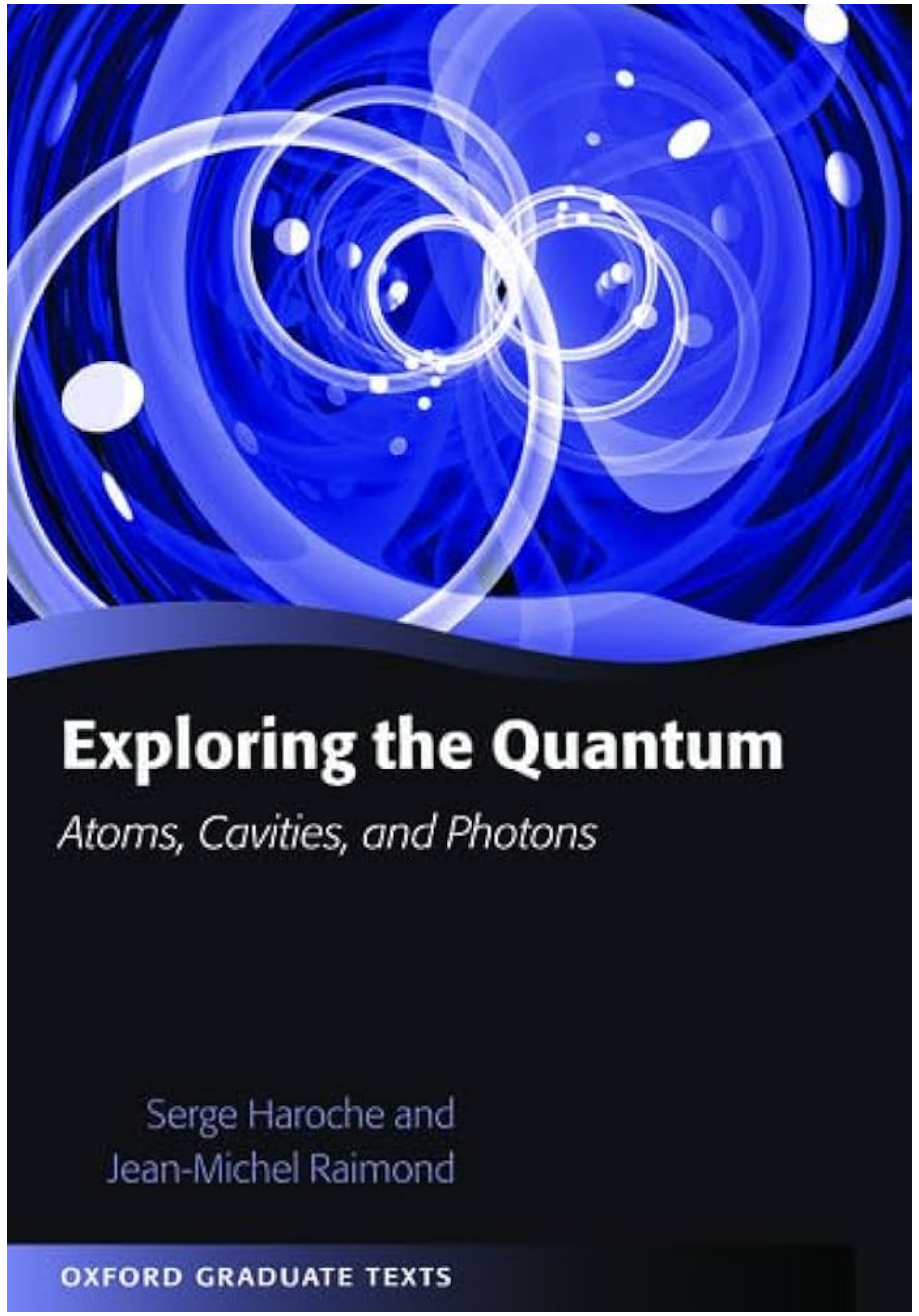
Oxford : Oxford University Press

1st ed.; 2007

Available Online

PHYS-344: **QUANTUM** MECHANICS FOR **NON-PHYSICISTS**

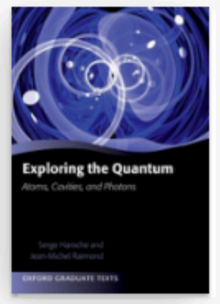
Reading



selected chapters

Modern physics-inclined text

2



BOOK

Exploring the quantum : atoms, cavities and photons

Haroche, S

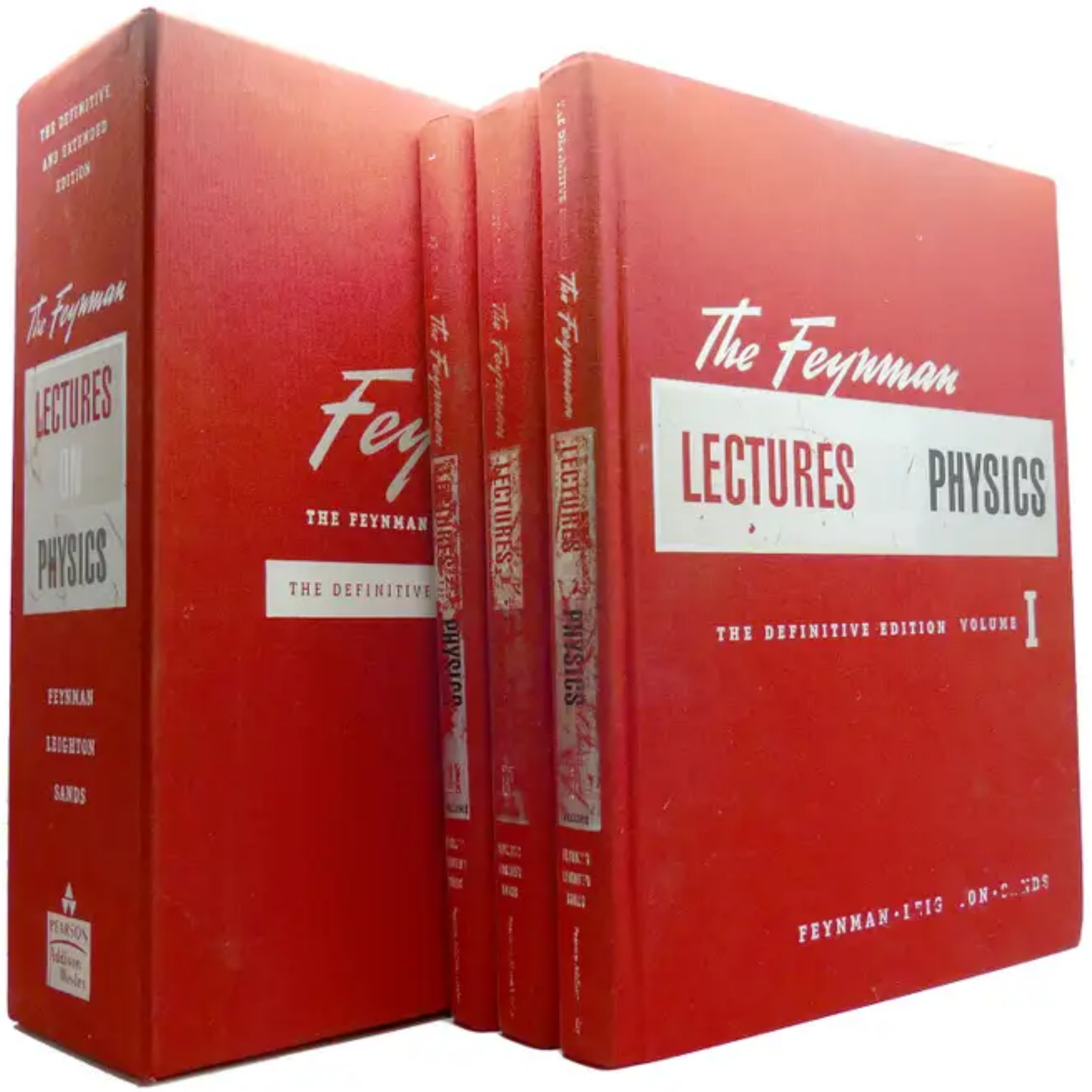
Oxford ; New York : Oxford University Press

1st ed.; 2006

Available Online

PHYS-344: **QUANTUM** MECHANICS FOR **NON-PHYSICISTS**

Reading



Quick reference on anything Physics

Free online version @ https://www.feynmanlectures.caltech.edu

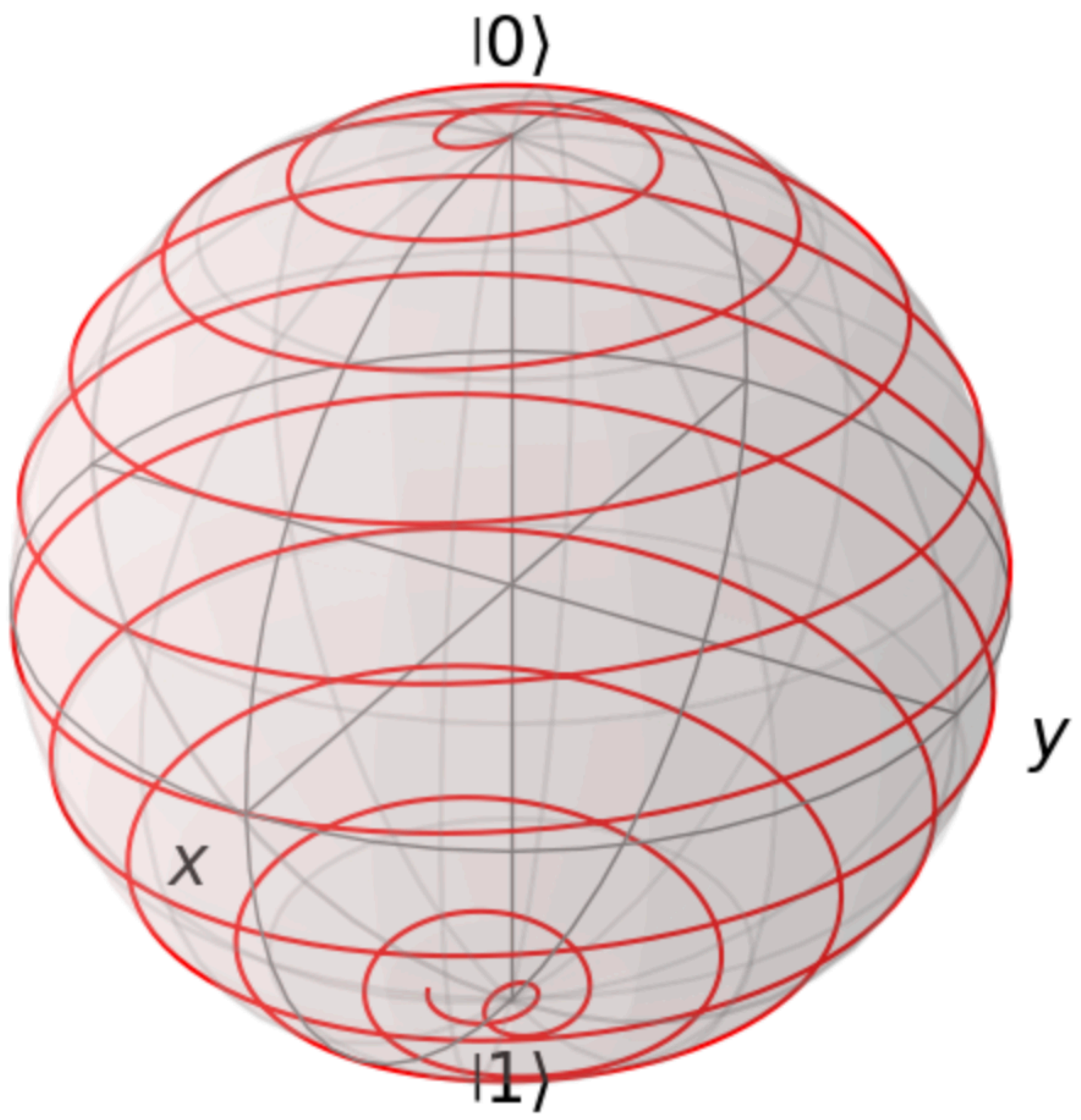
PHYS-344: **QUANTUM** MECHANICS FOR **NON-PHYSICISTS**

Exercises based on QuTiP in Python

```python
time_list = np.linspace(0, 11, 1001) # [ns] time points
f_q = 1 # [GHz] qubit frequency
f_d = 1 # [GHz] drive frequency
g = 0.3 # [GHz] coupling strength
epsilon = 1 # constant drive

omega_q = 2*np.pi*f_q
omega_d = 2*np.pi*f_d

# definition of the initial state
psi0 = basis(2,0) # ground state in 2 level system

# definition of the time-dependent hamiltonian
H = QobjEvo([-omega_q/2*sigmaz(),
            [sigmay(), lambda t: g*epsilon*np.sin(omega_d*t)]])

# solve the Schrodinger equation
output = mesolve(H, psi0, time_list, [], [sigmax(), sigmay(), sigmaz()])
```

```python
# plot on Bloch sphere
b = Bloch()
b.make_sphere()

# settings of Bloch class
b.point_marker=["o"]
b.point_size=[25]

# plot the laboratory frame states (plot points)
b.add_points(output.expect, meth="l", colors="red")
b.render()
b.show()
```

Evolution of qubit's state
on Bloch sphere



https://qutip.org

Taketo Imaizumi

Don't miss
seminars on
Thursdays!