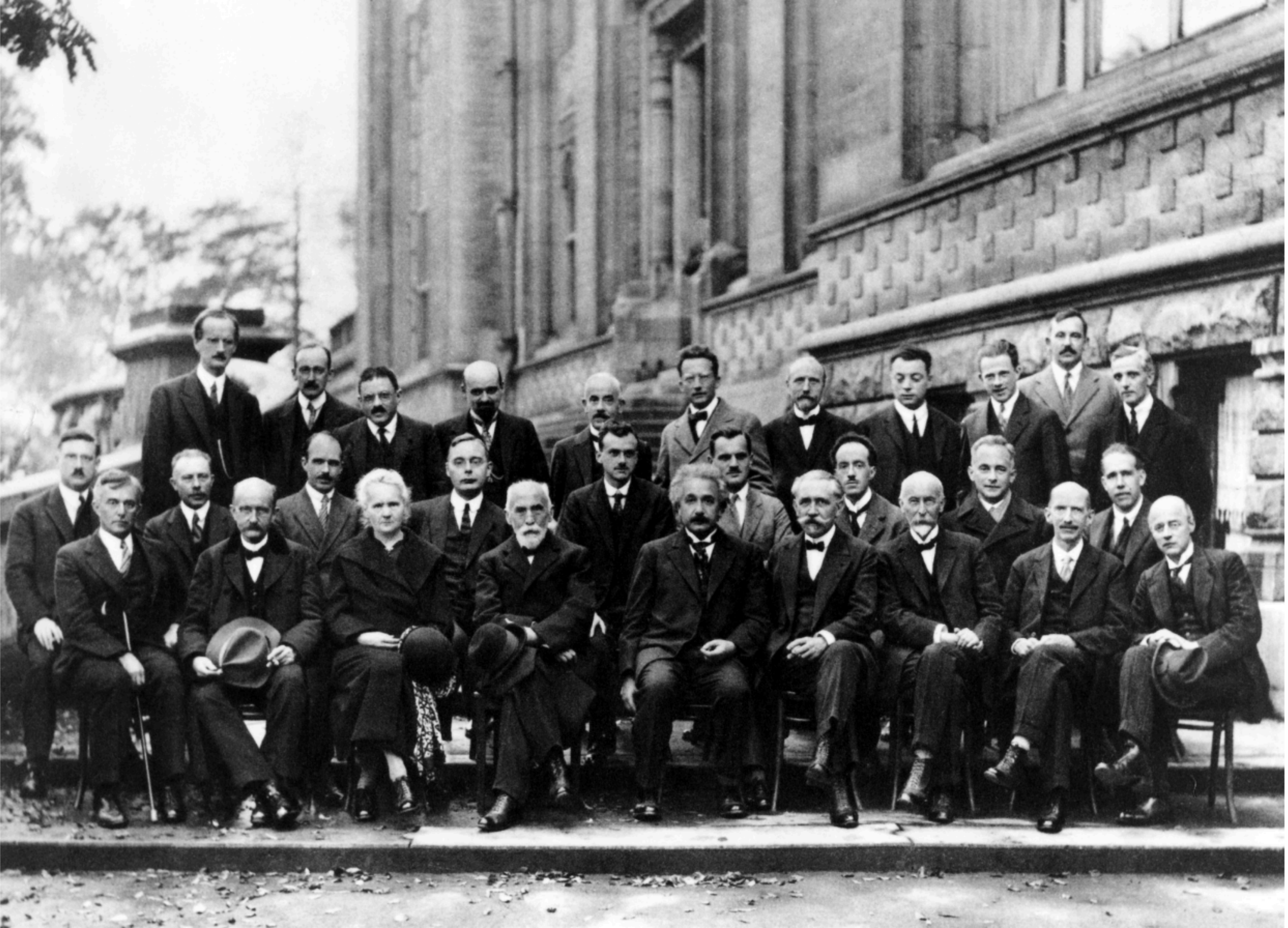


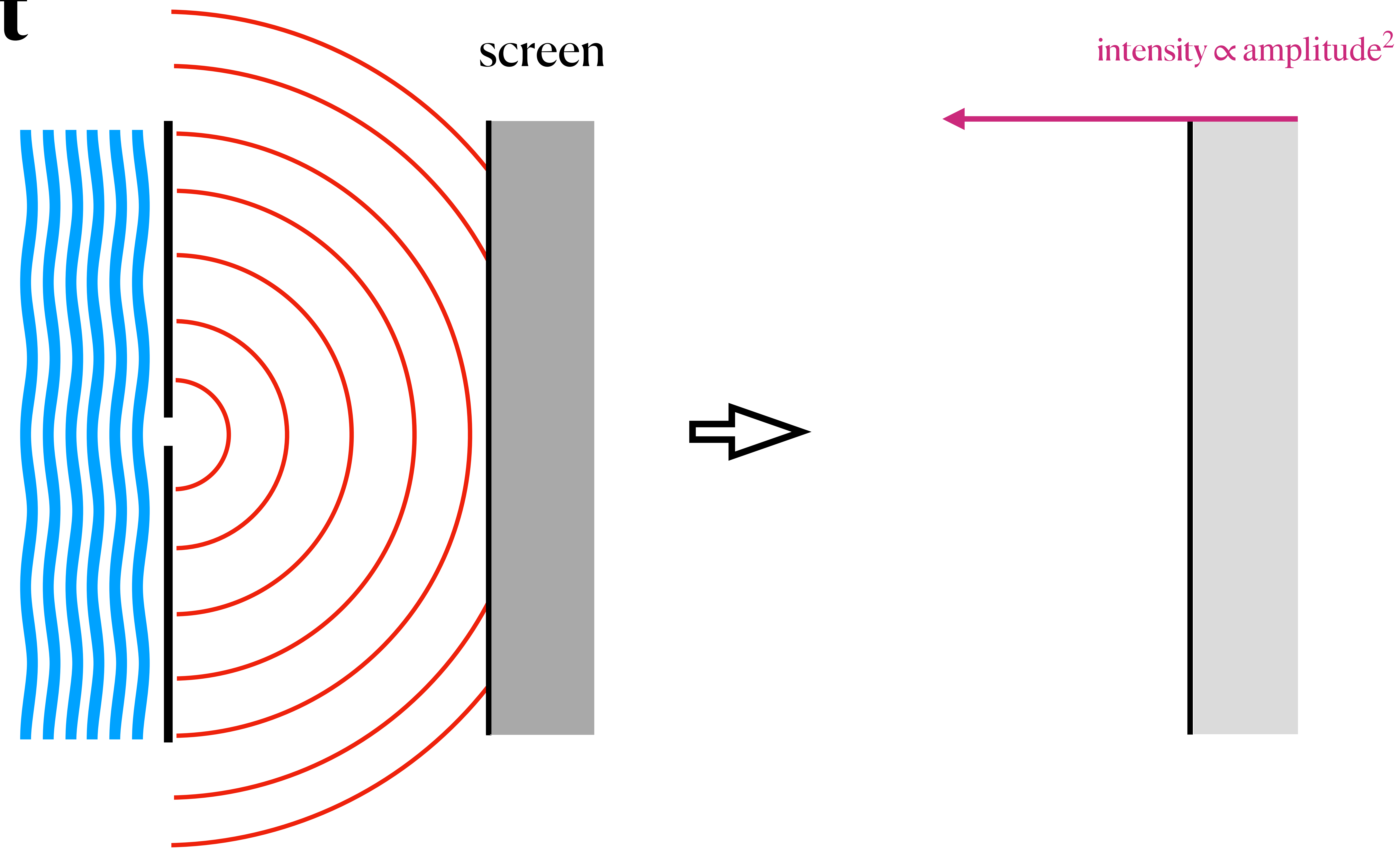
Philosophy of Physics

-

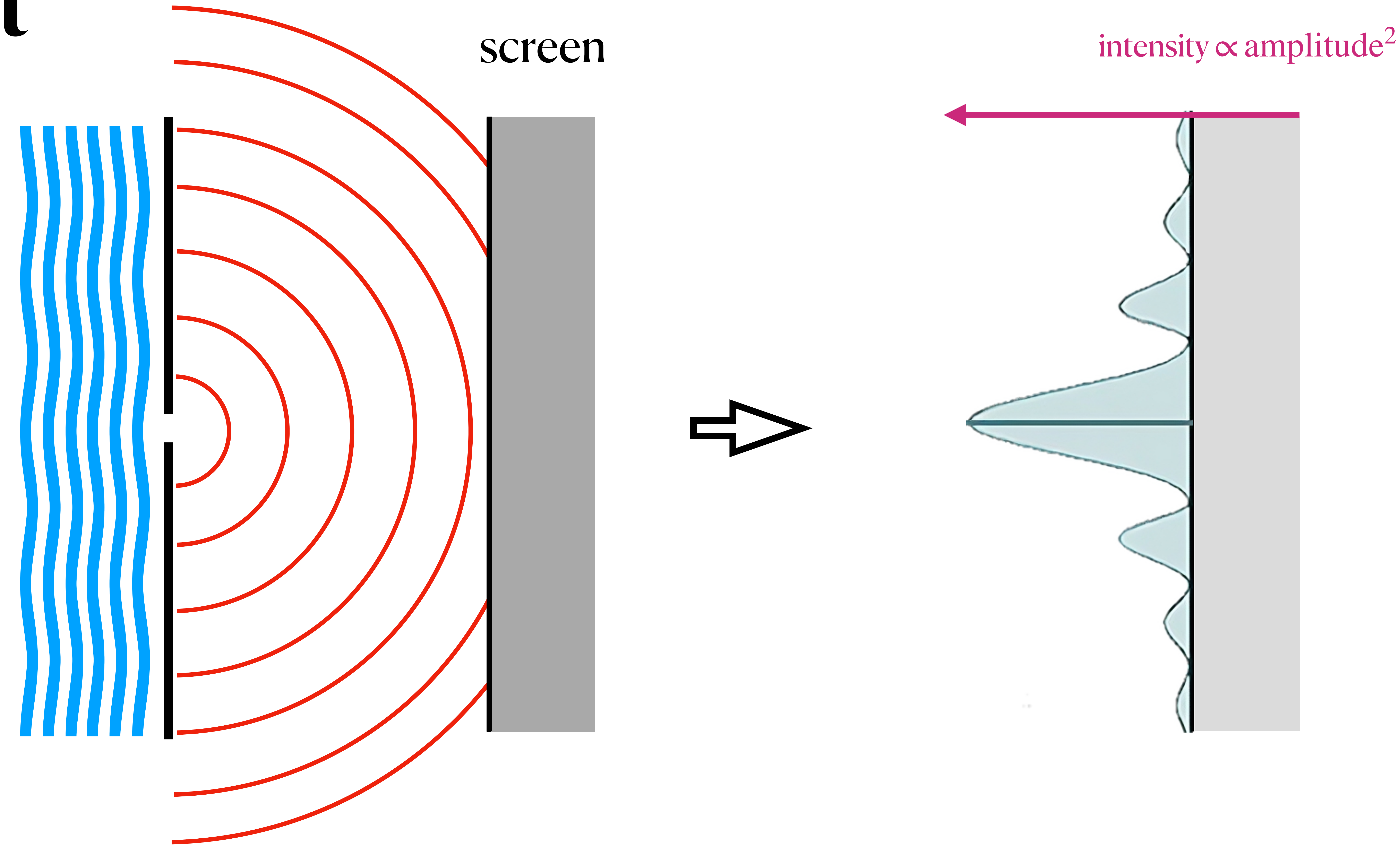
Lec. 6 - The world ~~is~~ can be quantum!

How weird
would it be if…

1-slit experiment with light



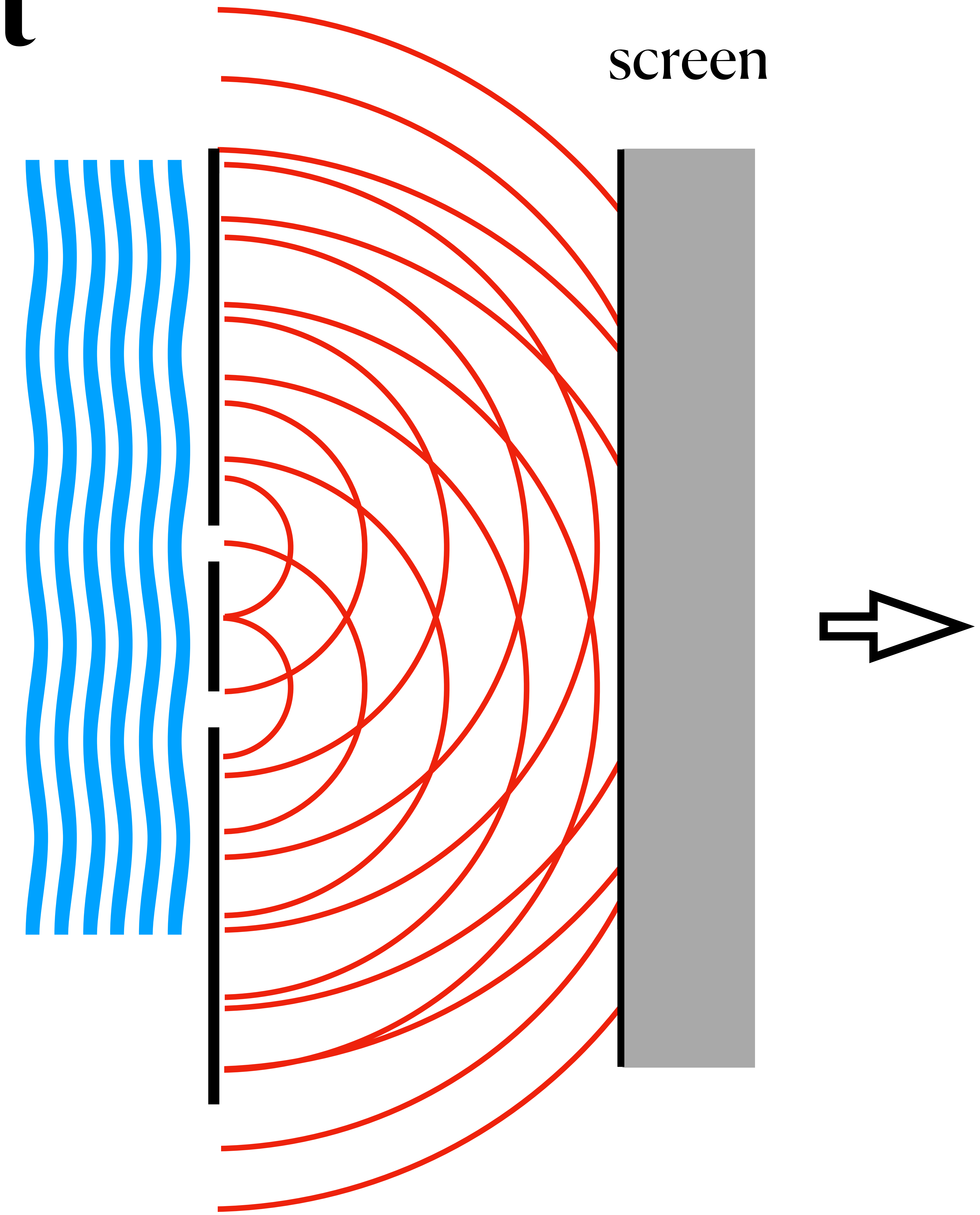
1-slit experiment with light

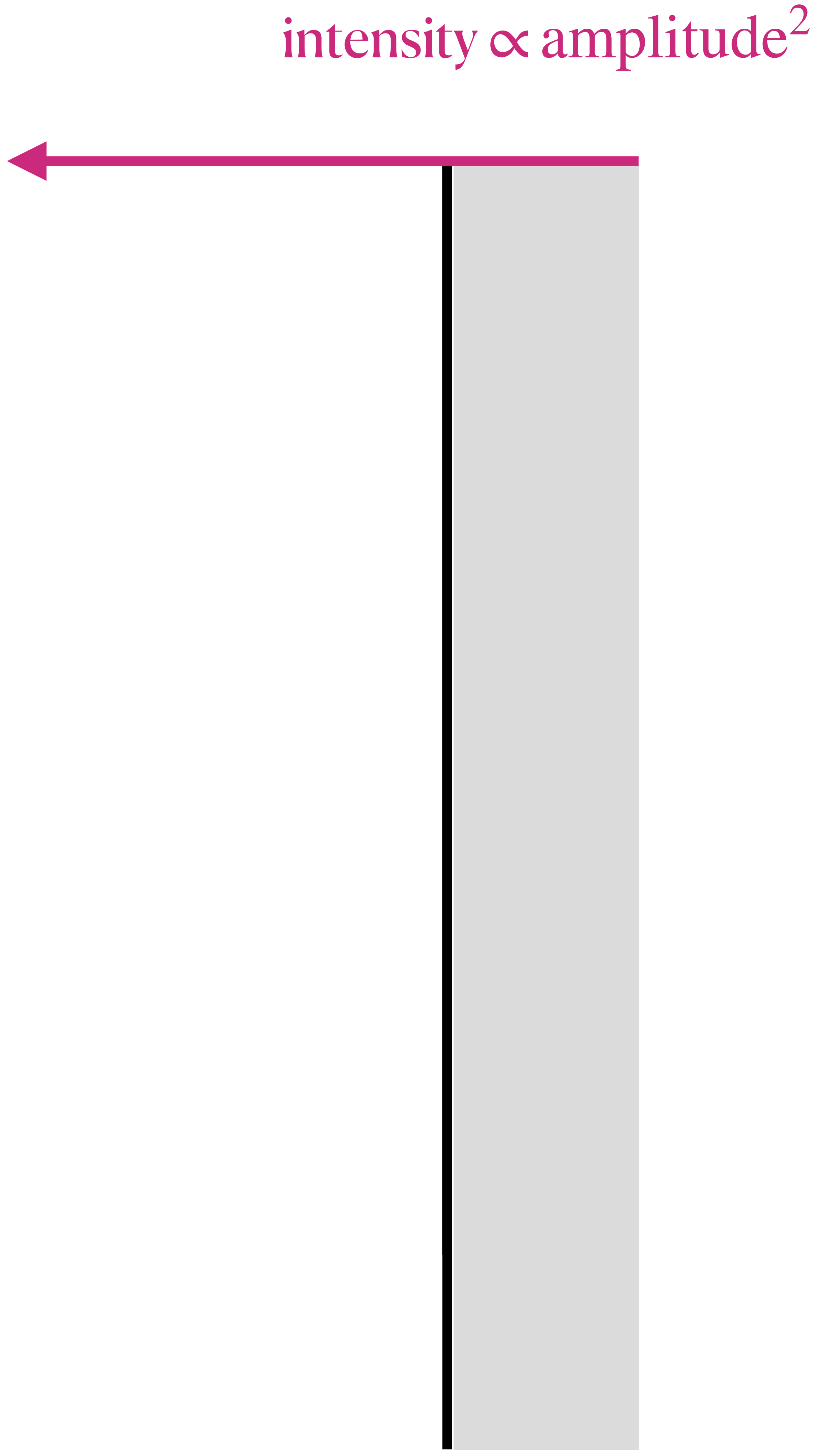


- light passes through the slit like when we throw a rock on a still lake

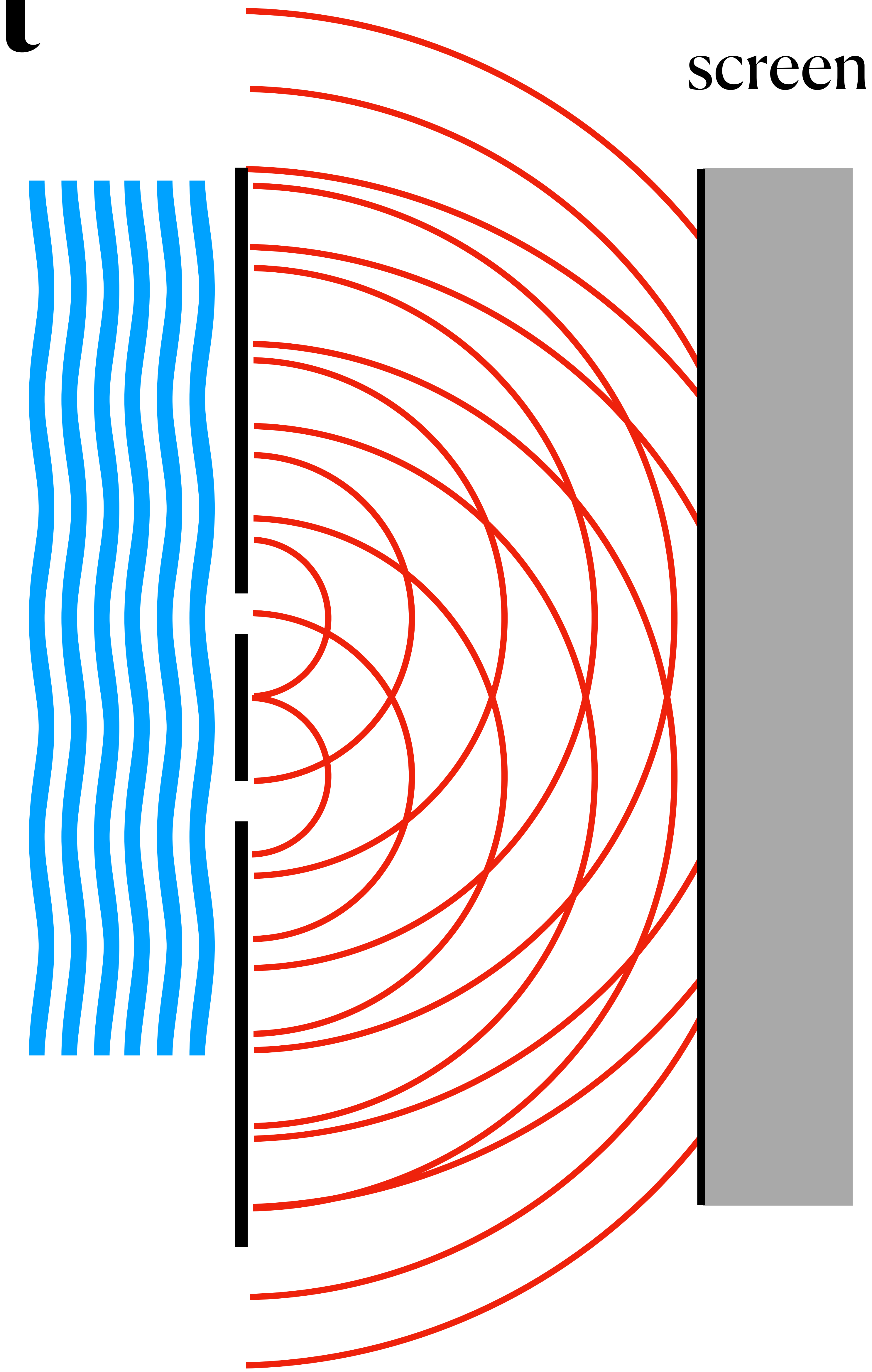
Single Slit Difraction Pattern

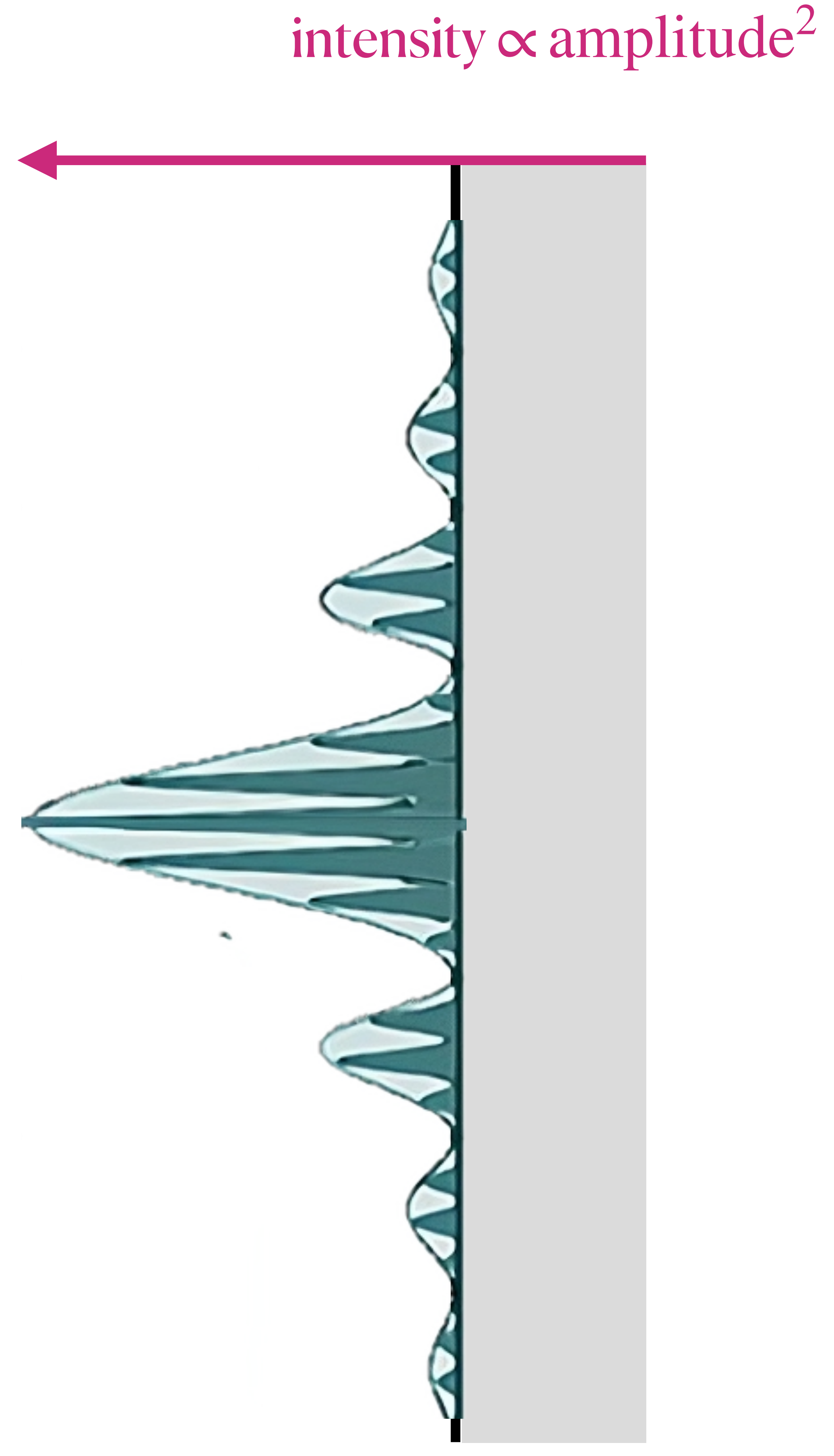
2-slit experiment with light





2-slit experiment with light

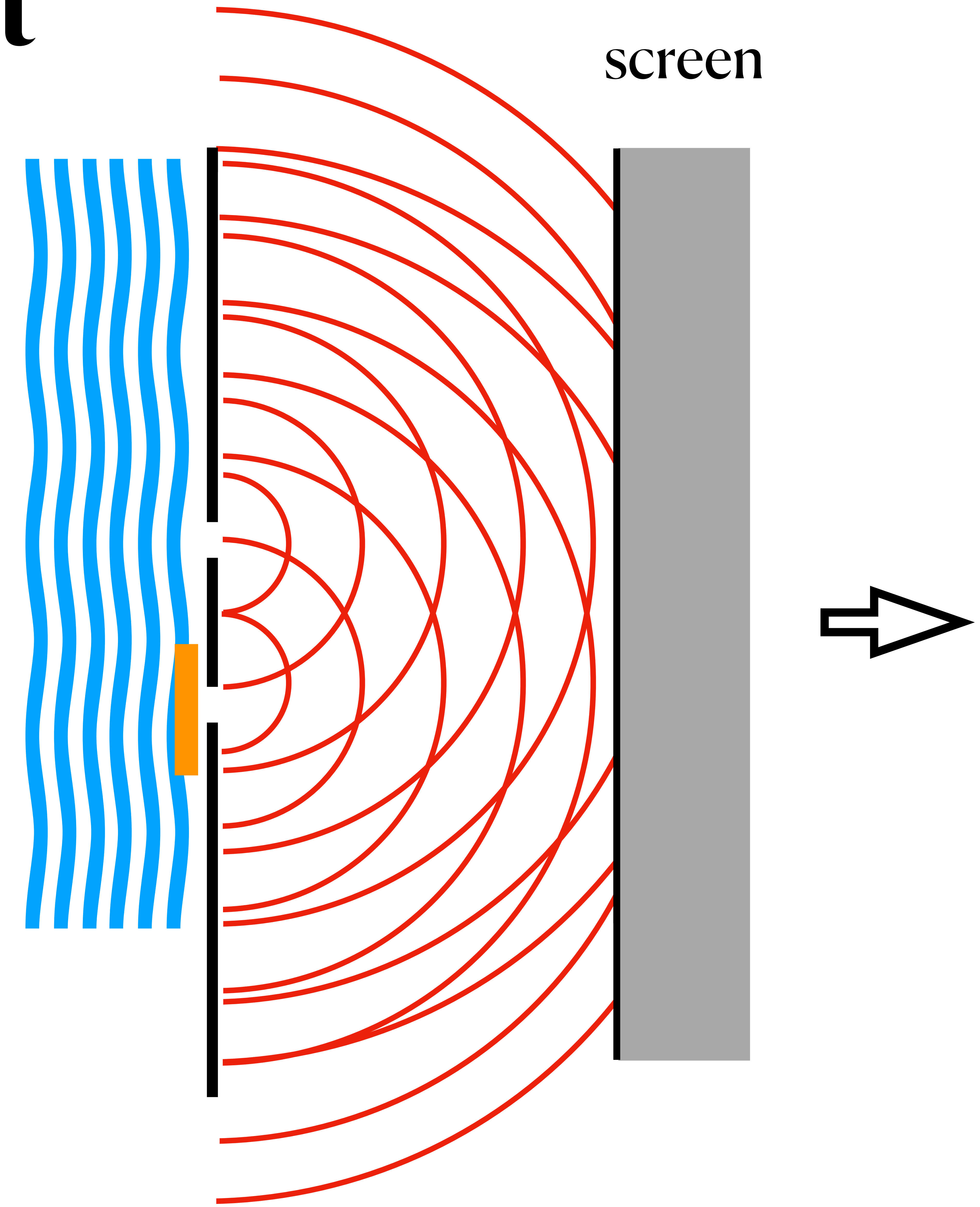


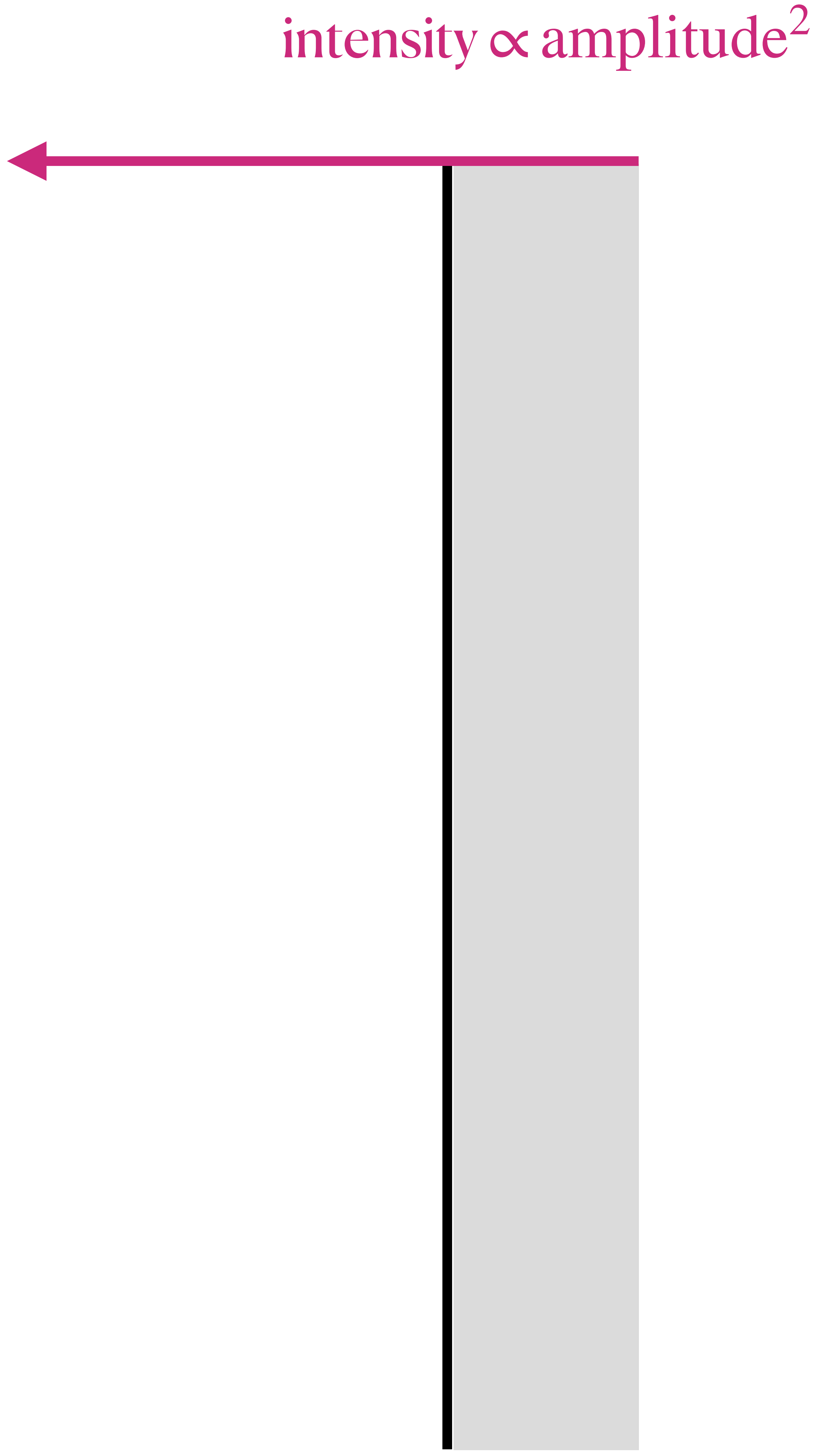


- we observe an interference pattern

~~2~~-slit experiment with light

close one slit!





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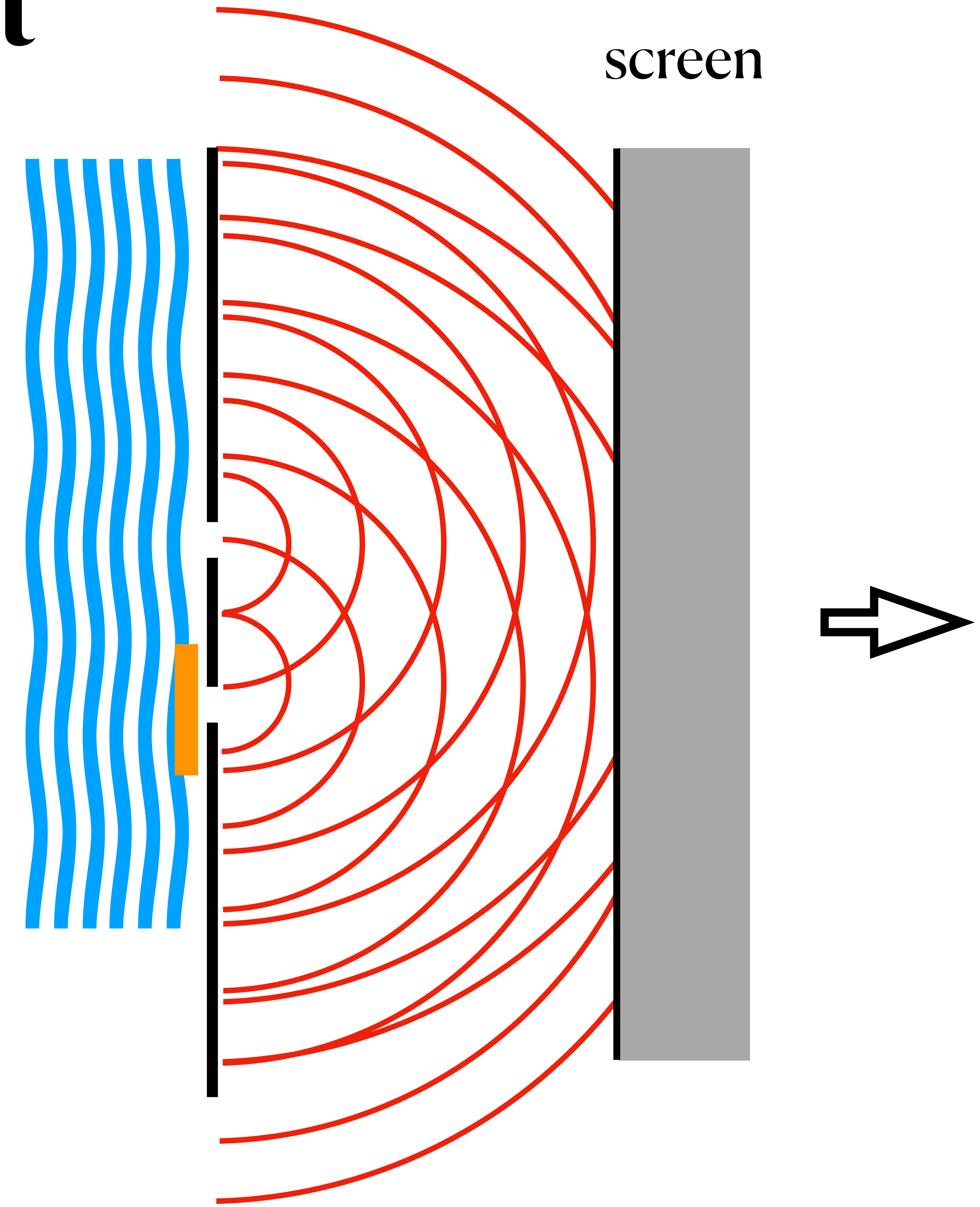
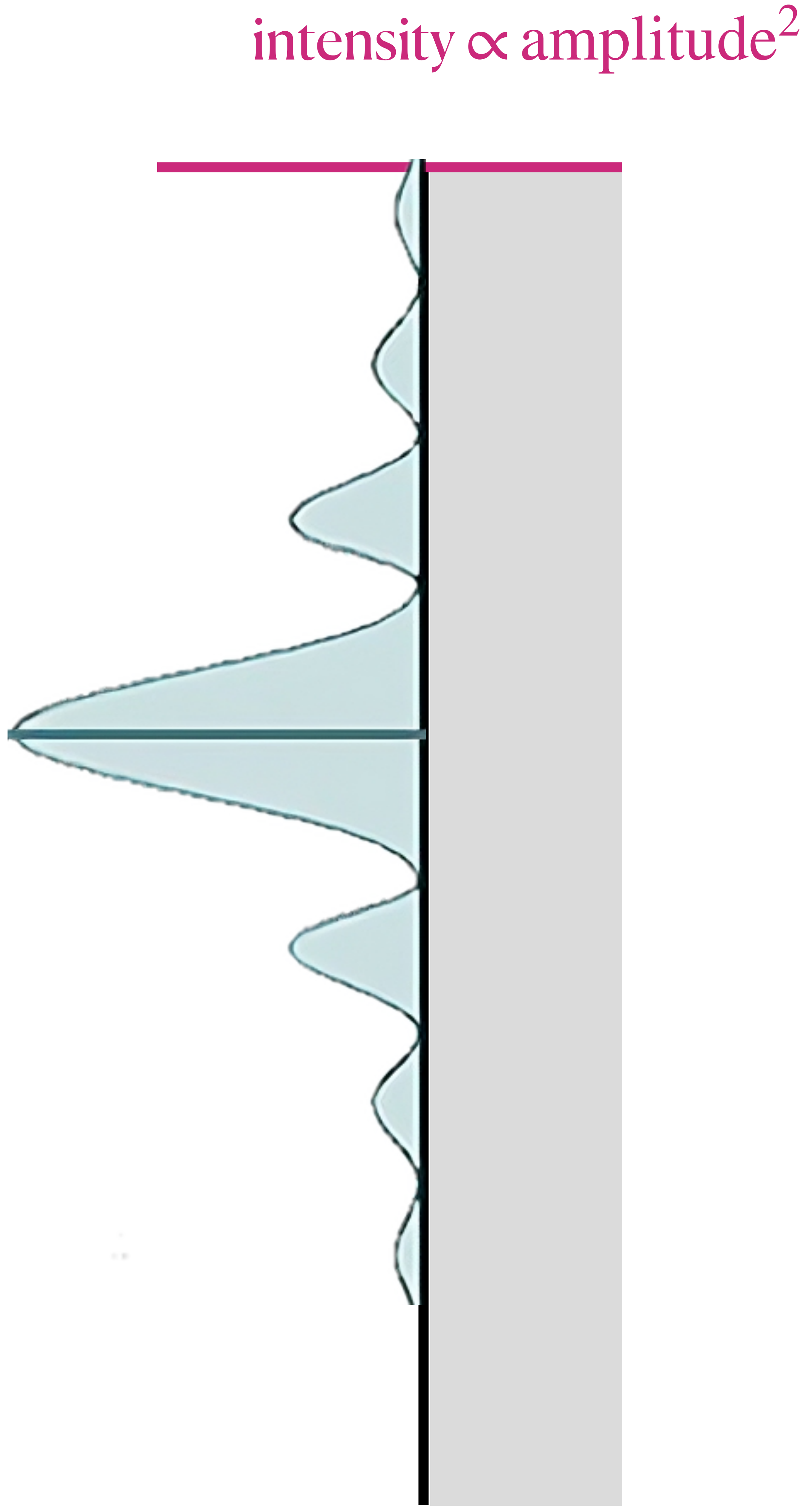
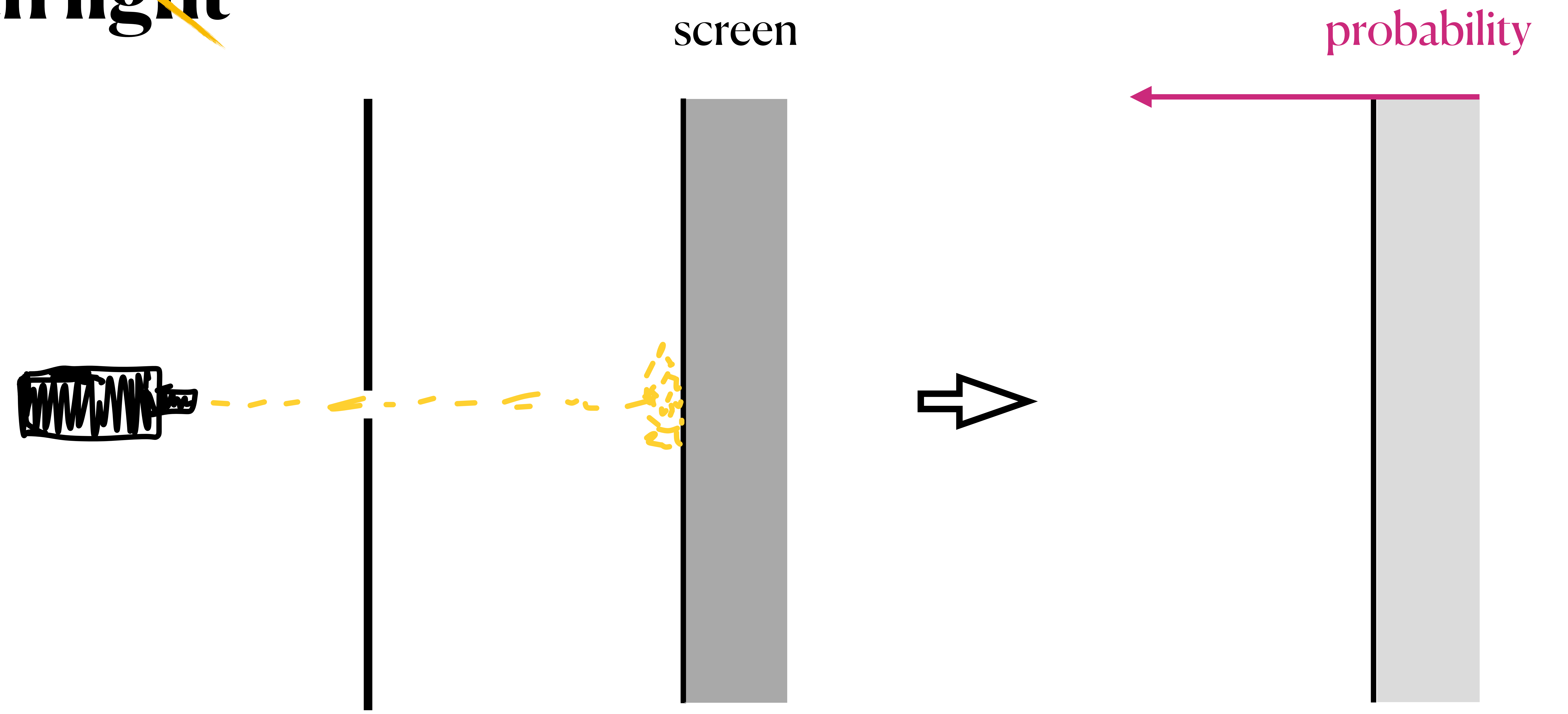
close one slit!



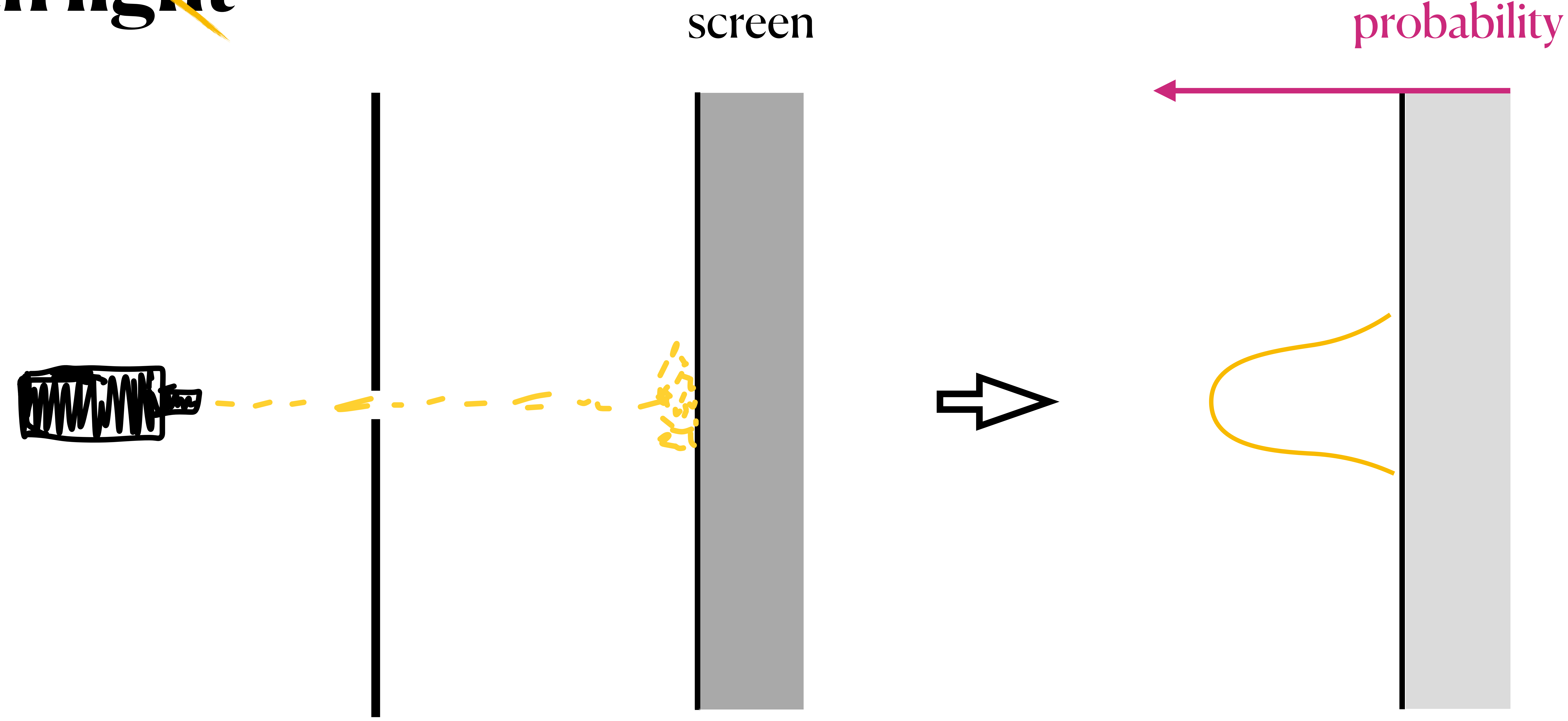


Double Slit Difraction Pattern

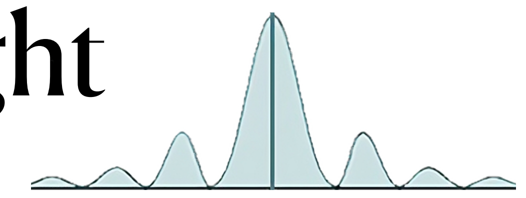
1-slit experiment with ~~light~~ particles!



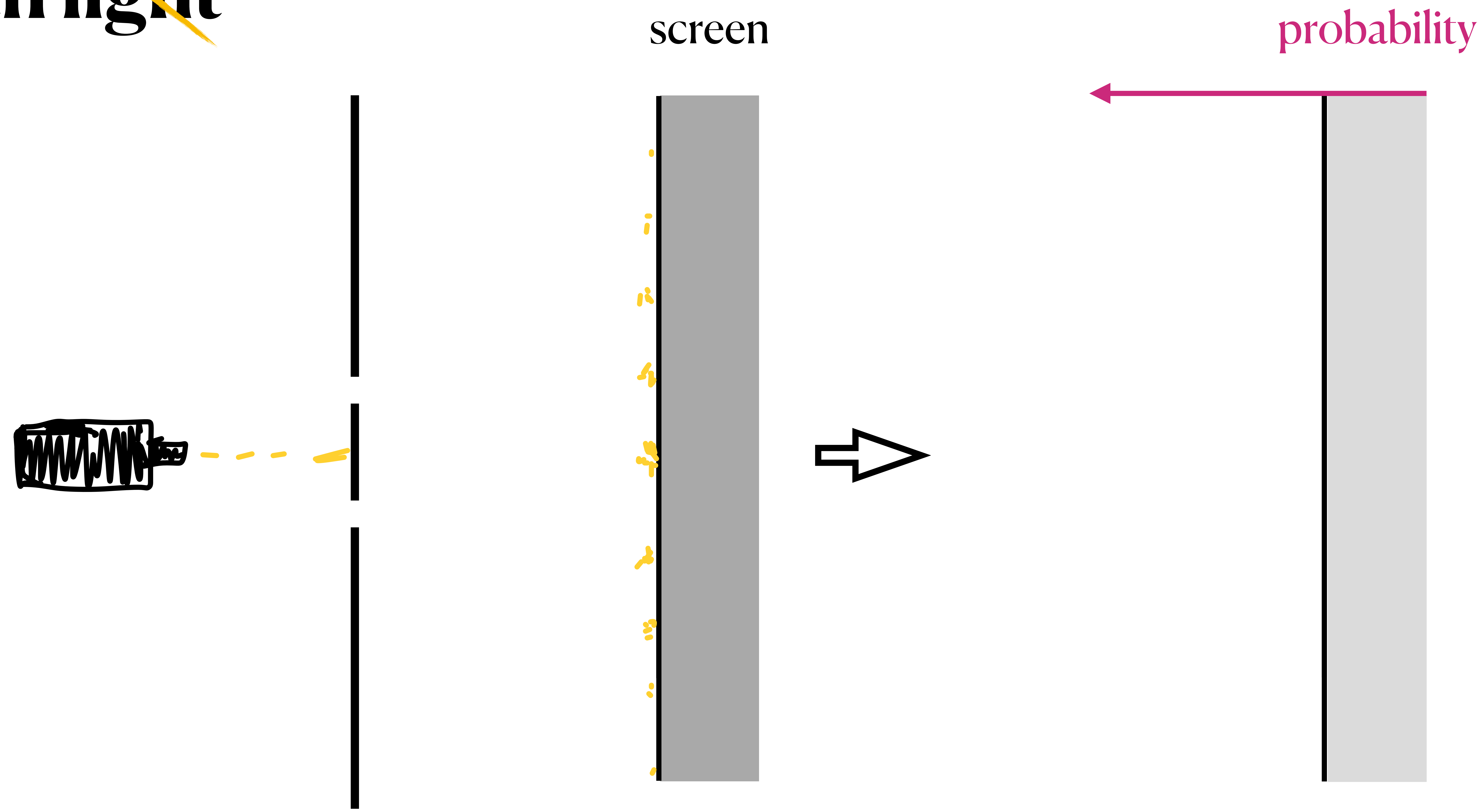
1-slit experiment with ~~light~~ particles!



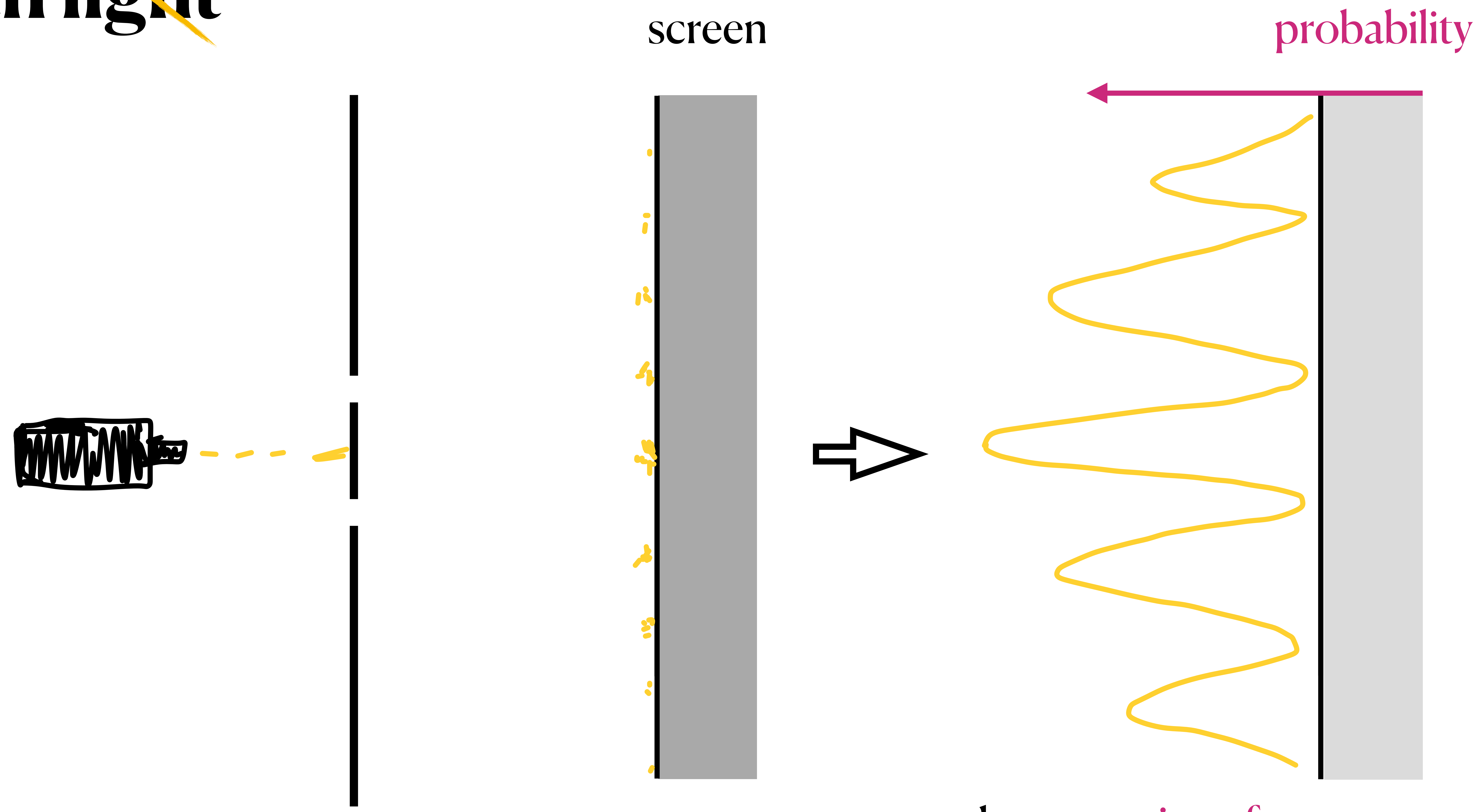
- just like for light



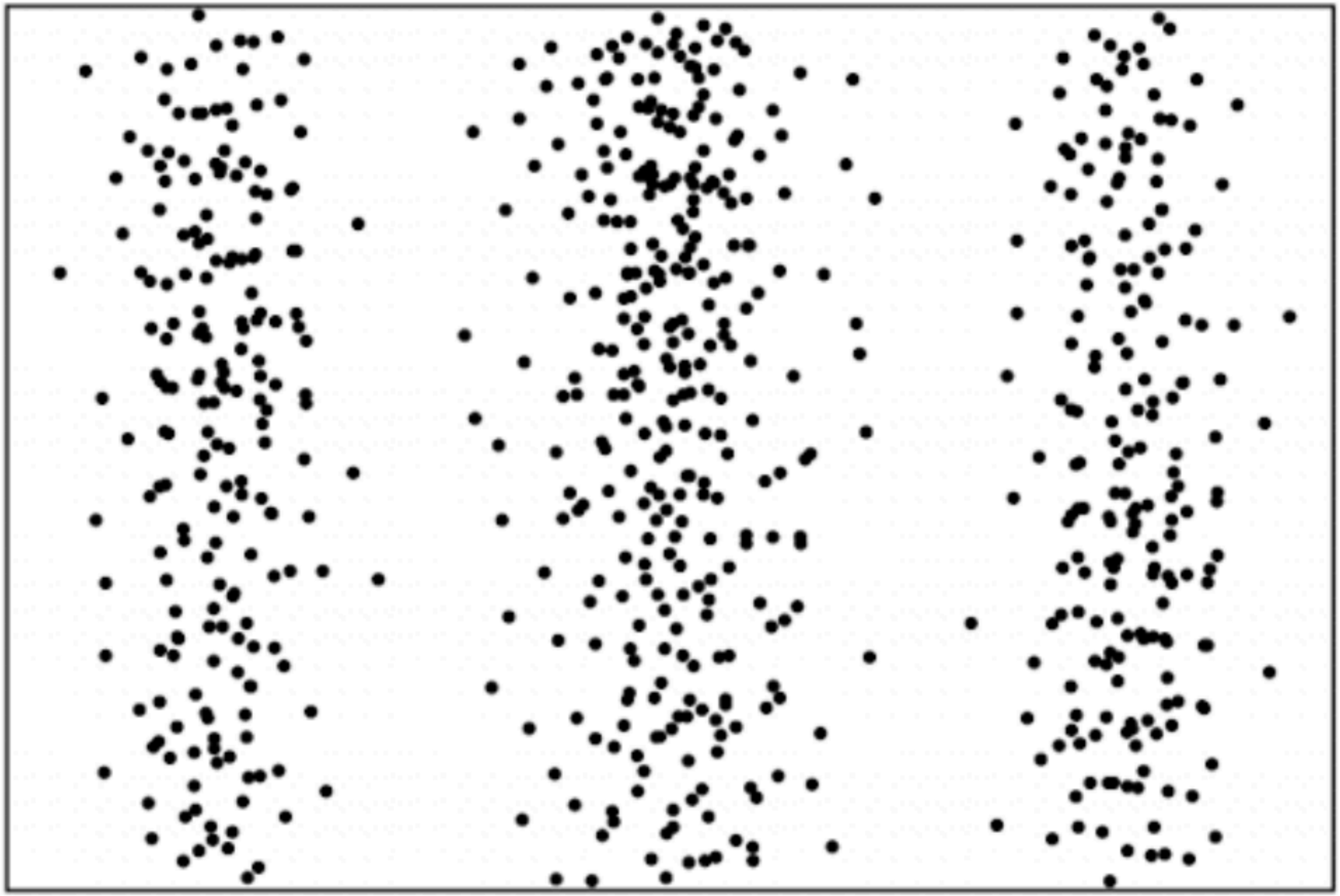
2-slit experiment with ~~light~~ particles!



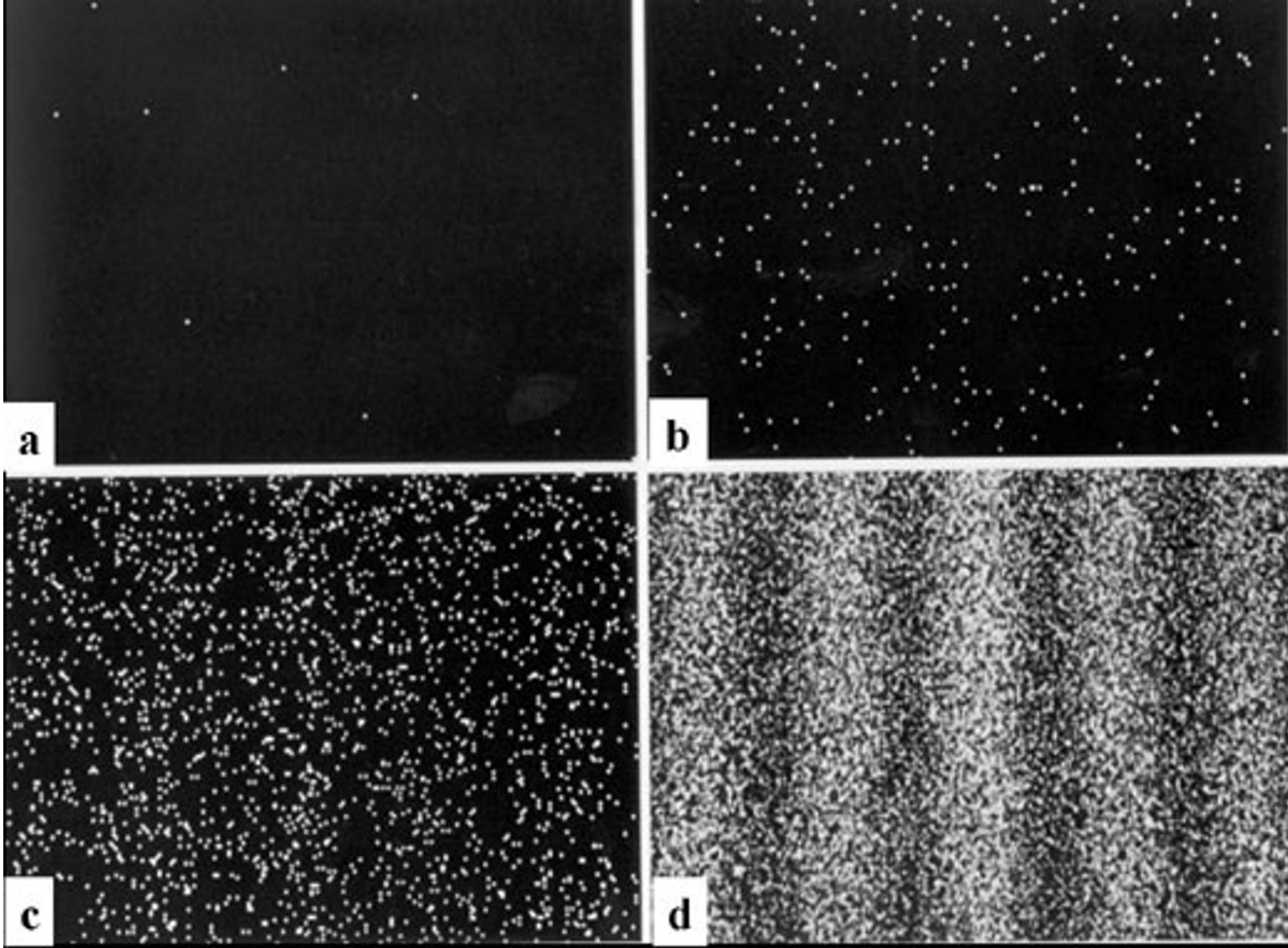
2-slit experiment with ~~light~~ particles!



- we observe an interference pattern!

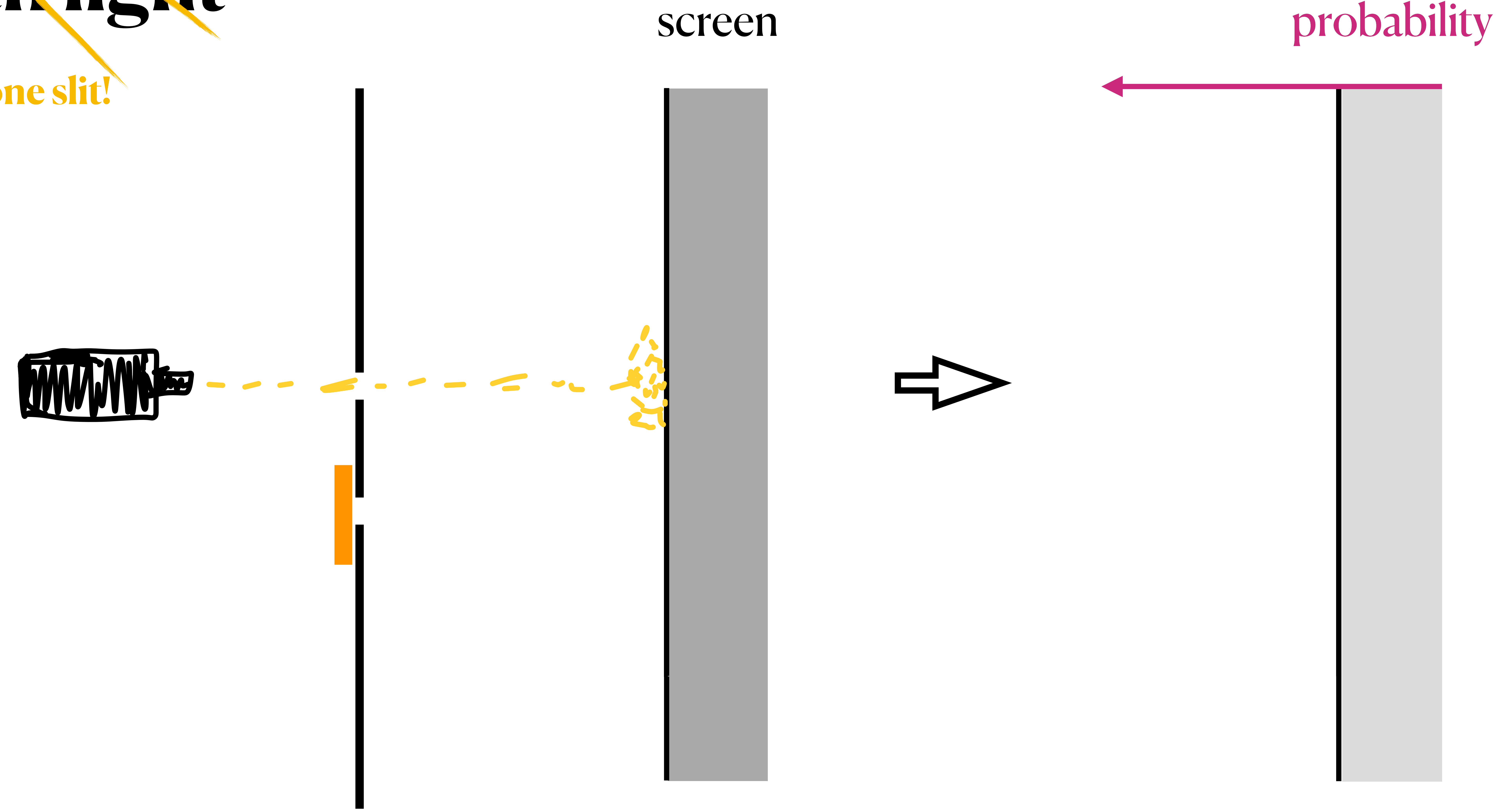


Double Slit Experiment with Electrons



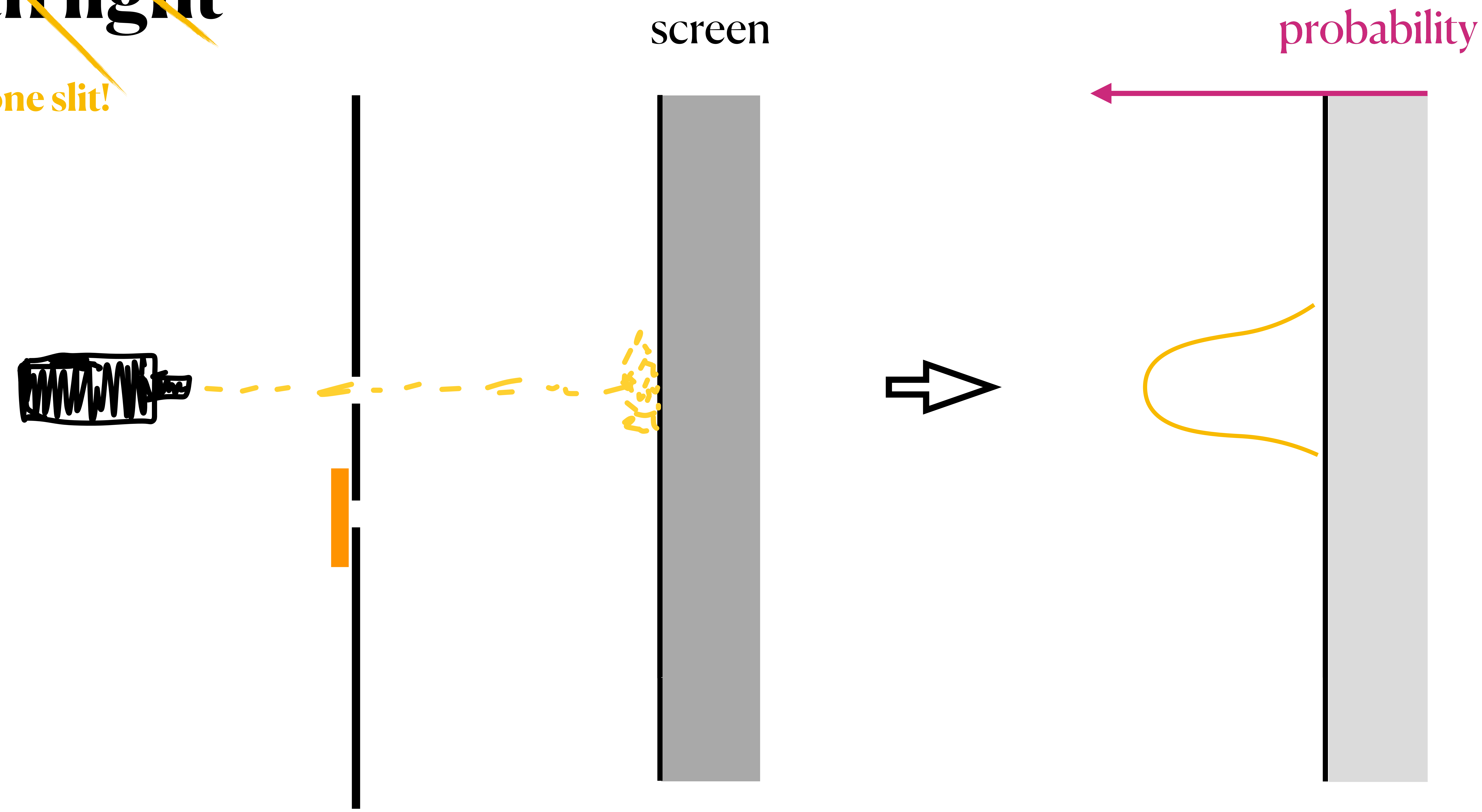
~~2~~-slit experiment with ~~light~~ particles!

close one slit!



1 ~~2~~-slit experiment with ~~light~~ particles!

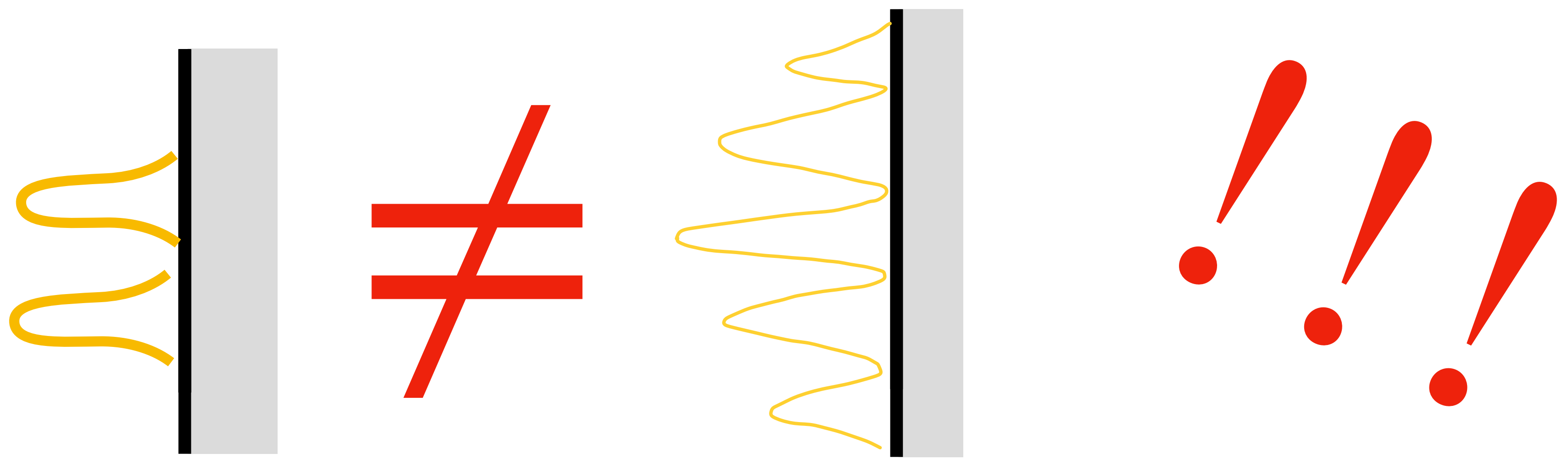
close one slit!



2-slit experiment with ~~light~~ particles!

- maybe the particles are just knocking on a weird way against the slits?

- even after closing one or the other slit and adding the particle's on the screen:



2-slit experiment with ~~light~~ particles!

- maybe the particles are scattering each other off… try one at the time?

2-slit experiment with ~~light~~ particles!

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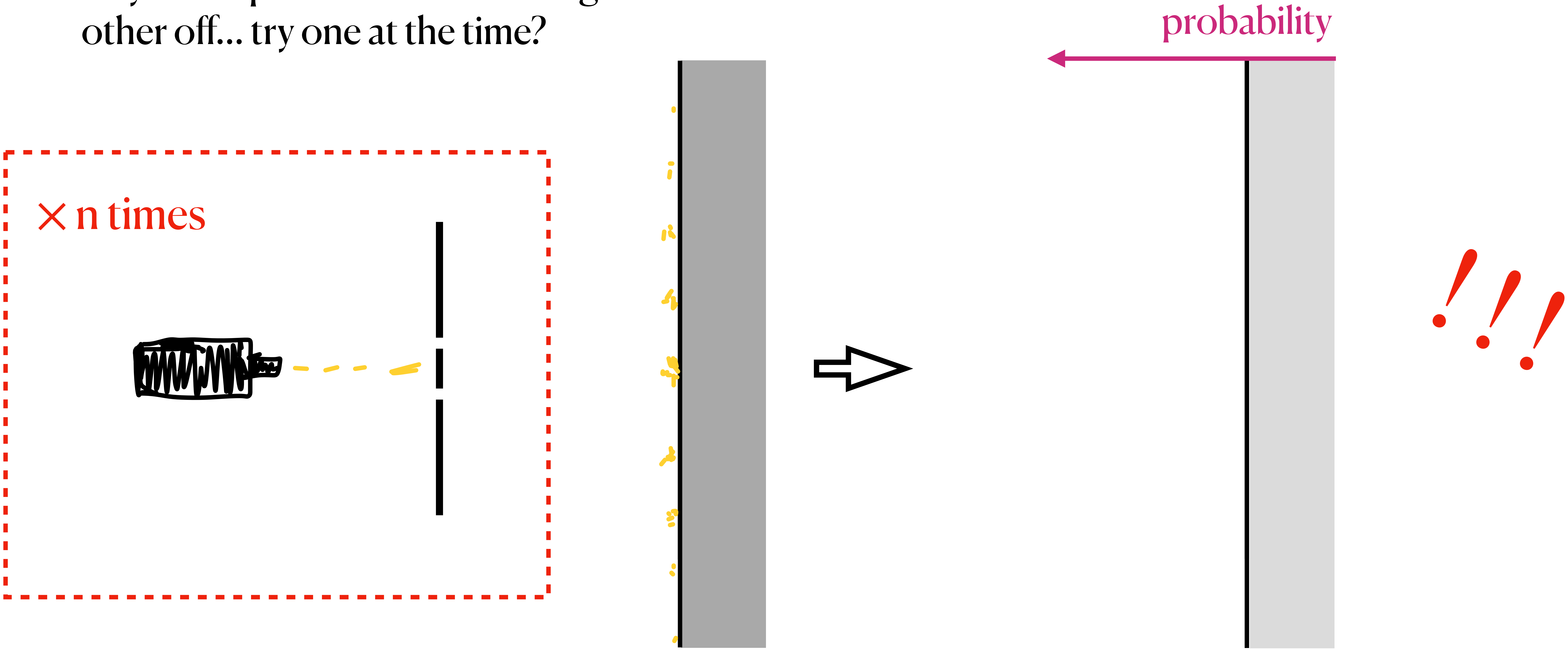

2-slit experiment with ~~light~~ particles!

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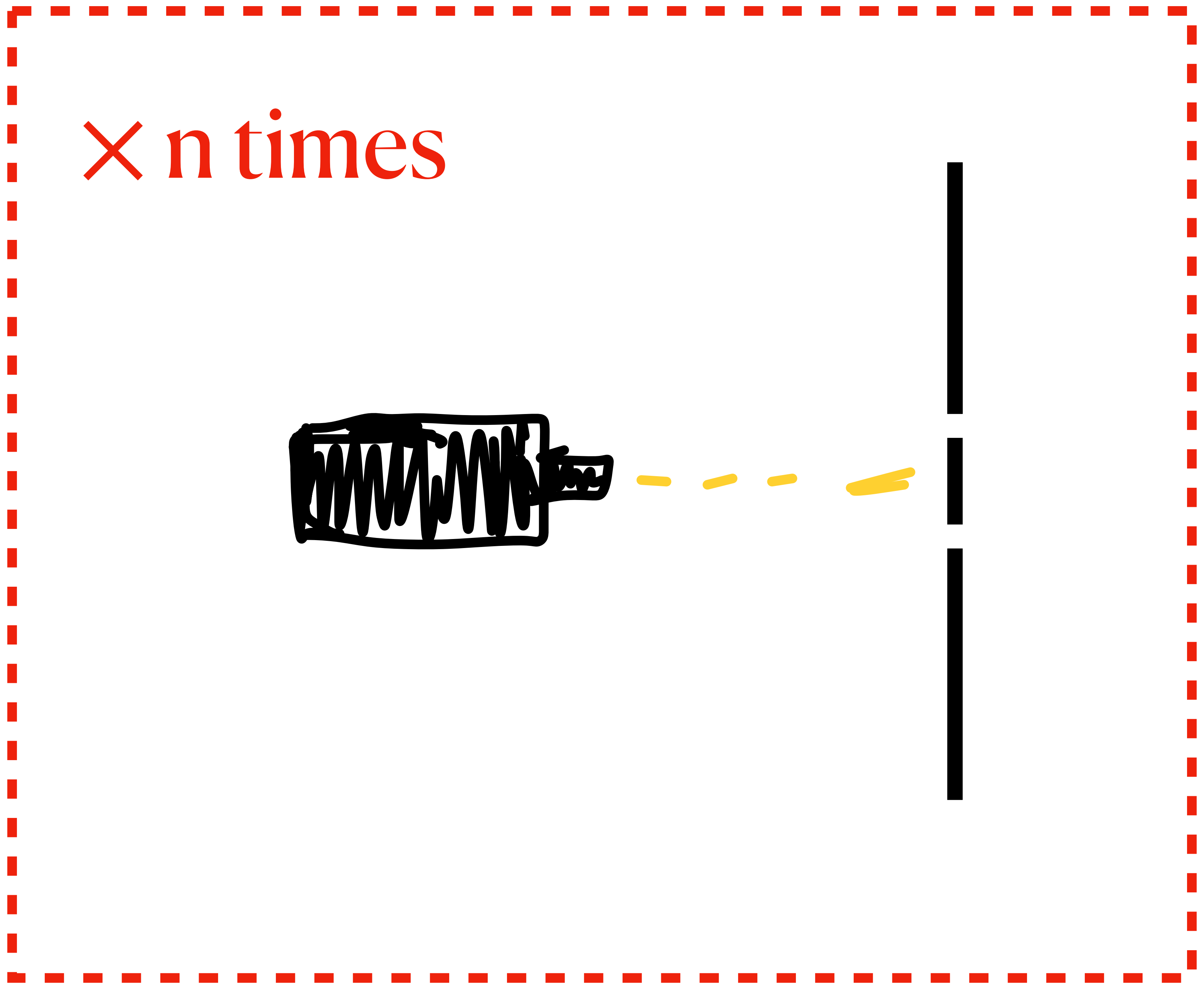
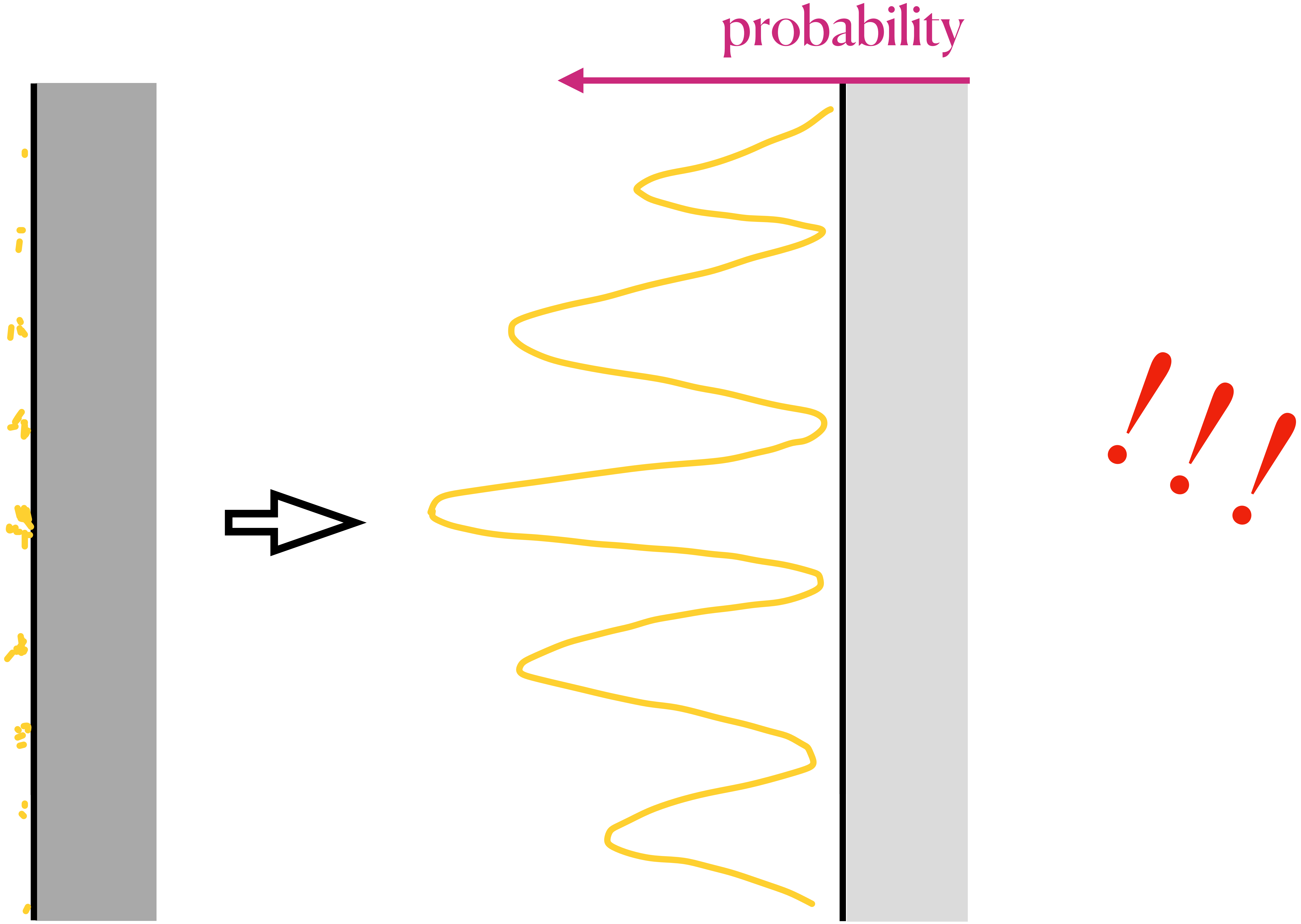




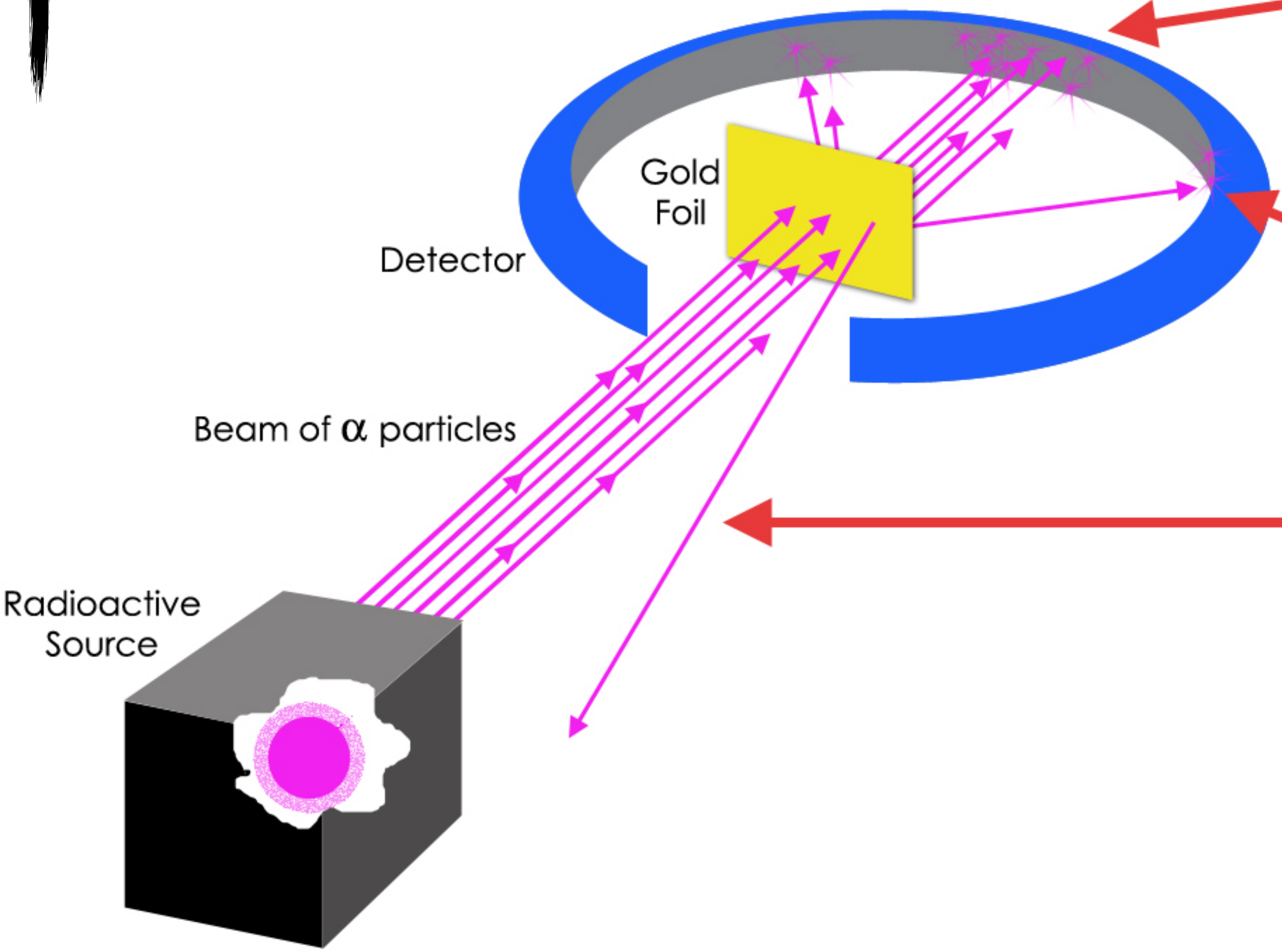
It is as if there is something that is going through both slits, but it cannot be the particle since whenever we try and see the particle going through one or the other slit, everything seems as expected!

Thoughts?

- if you don't know, speculate;
- if you know, explain and discuss with the others

How did we get here?

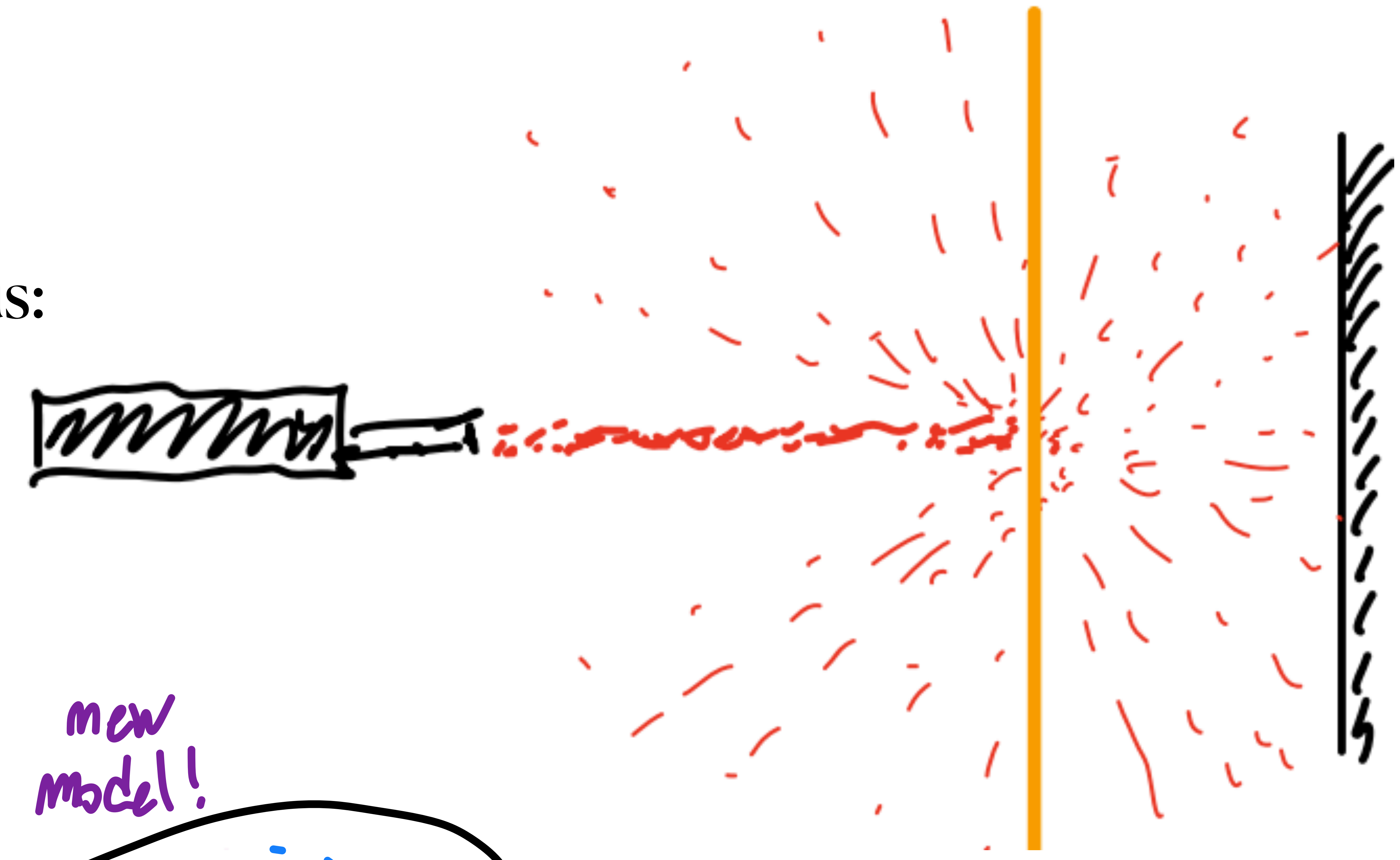
1) Rutherford experiment:

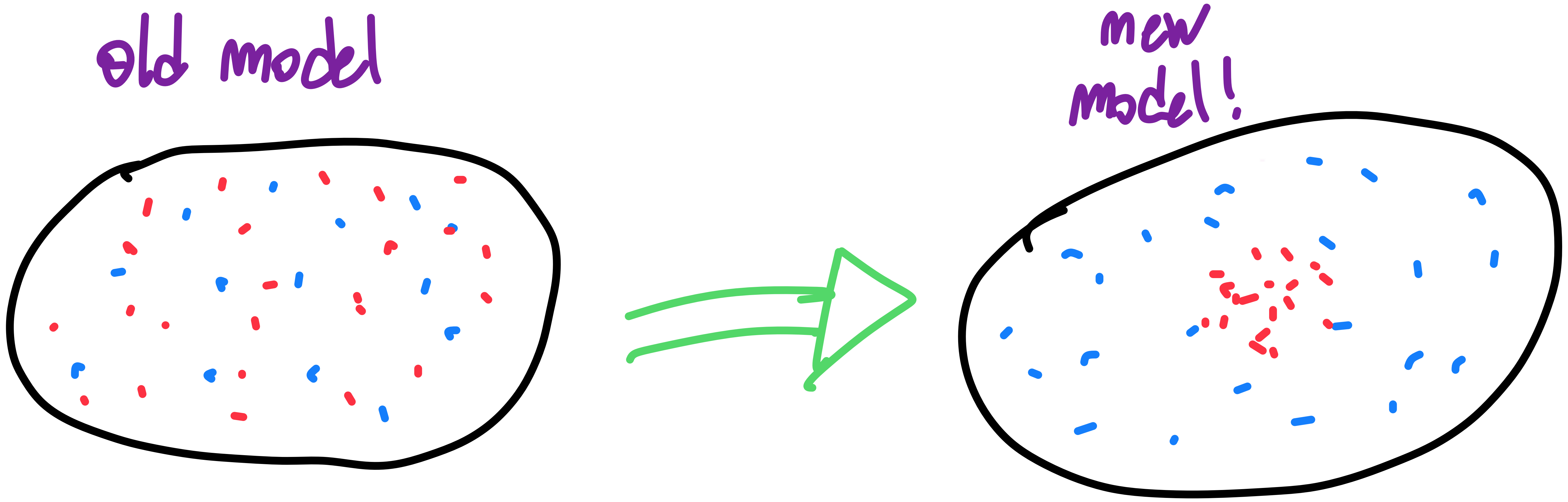


observation	interpretation
Most α particles travel through the foil undeflected	The atom is mostly empty space
Some α particles are deflected by small angles	The nucleus is positively charged, as is the α particle
Occasionally, an α particle travels back from the foil	The nucleus carries most of the atom's mass

How did we get here?

1) Rutherford model of the nucleus:

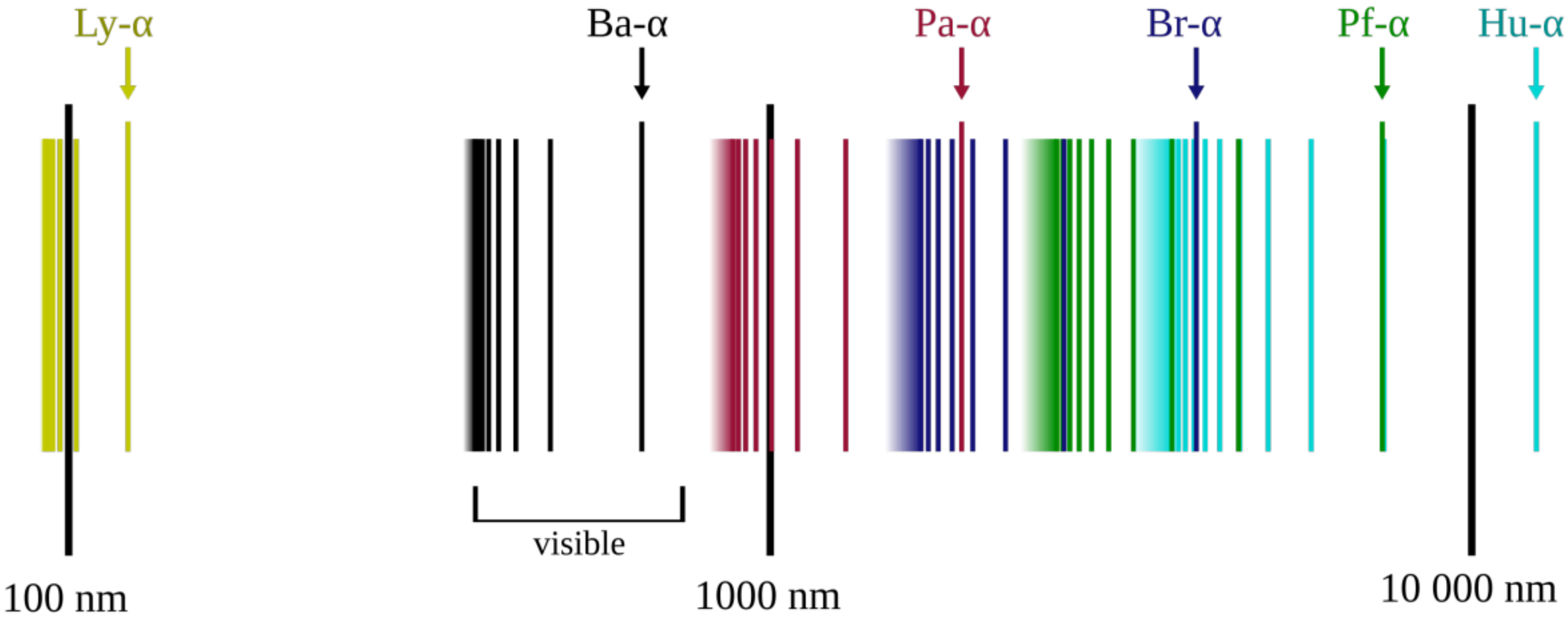




- Problem! accelerated charged particles emit radiation, losing energy ⇒ atom unstable! ($\approx 10^{-11}$ s)

2) spectral lines: using classical physics, atoms should emit and absorb light on all frequencies!

spectral lines of hydrogen!



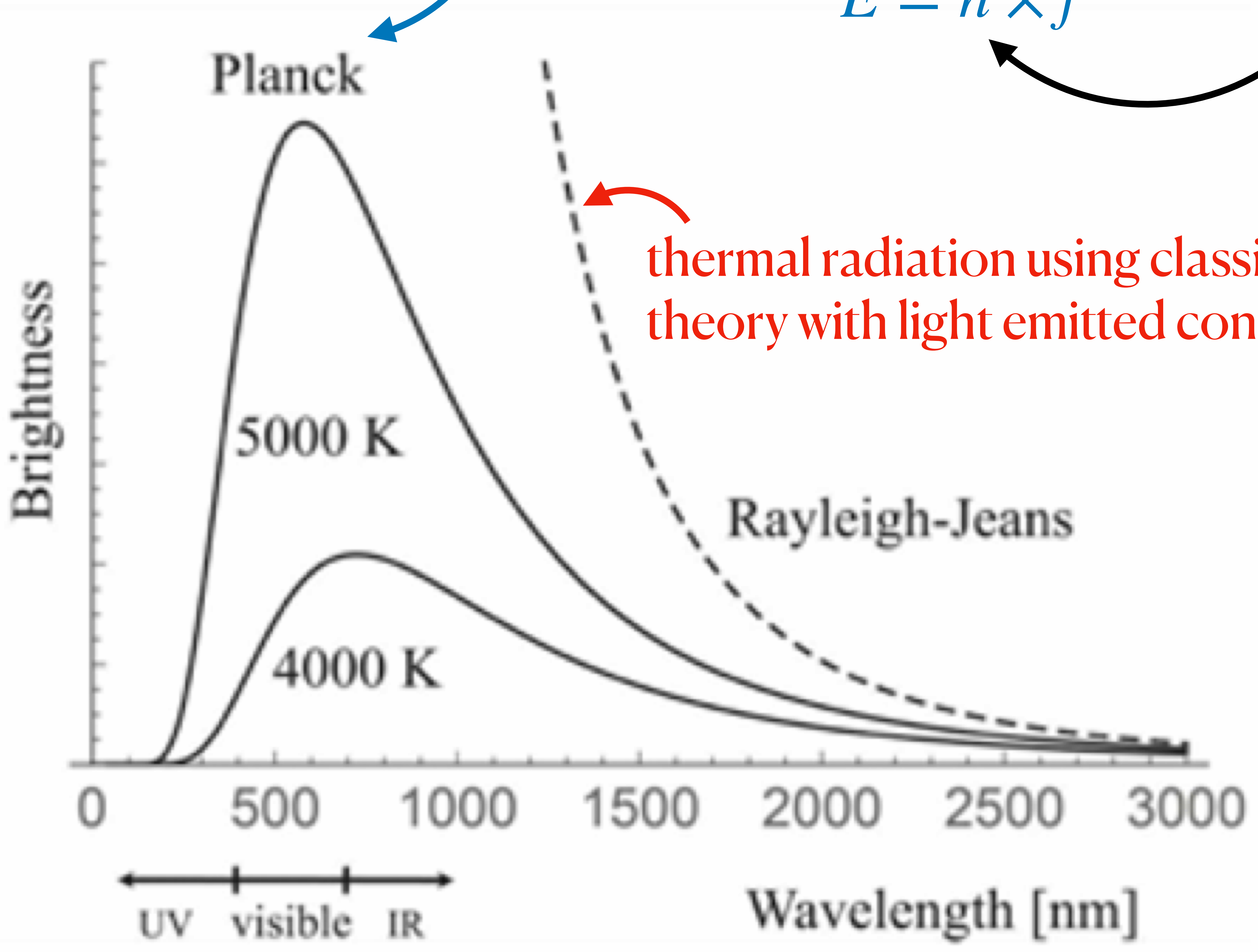
Why are spectral lines useful?

3) black-body radiation:

using light emitted discretely:

$$E = h \times f$$

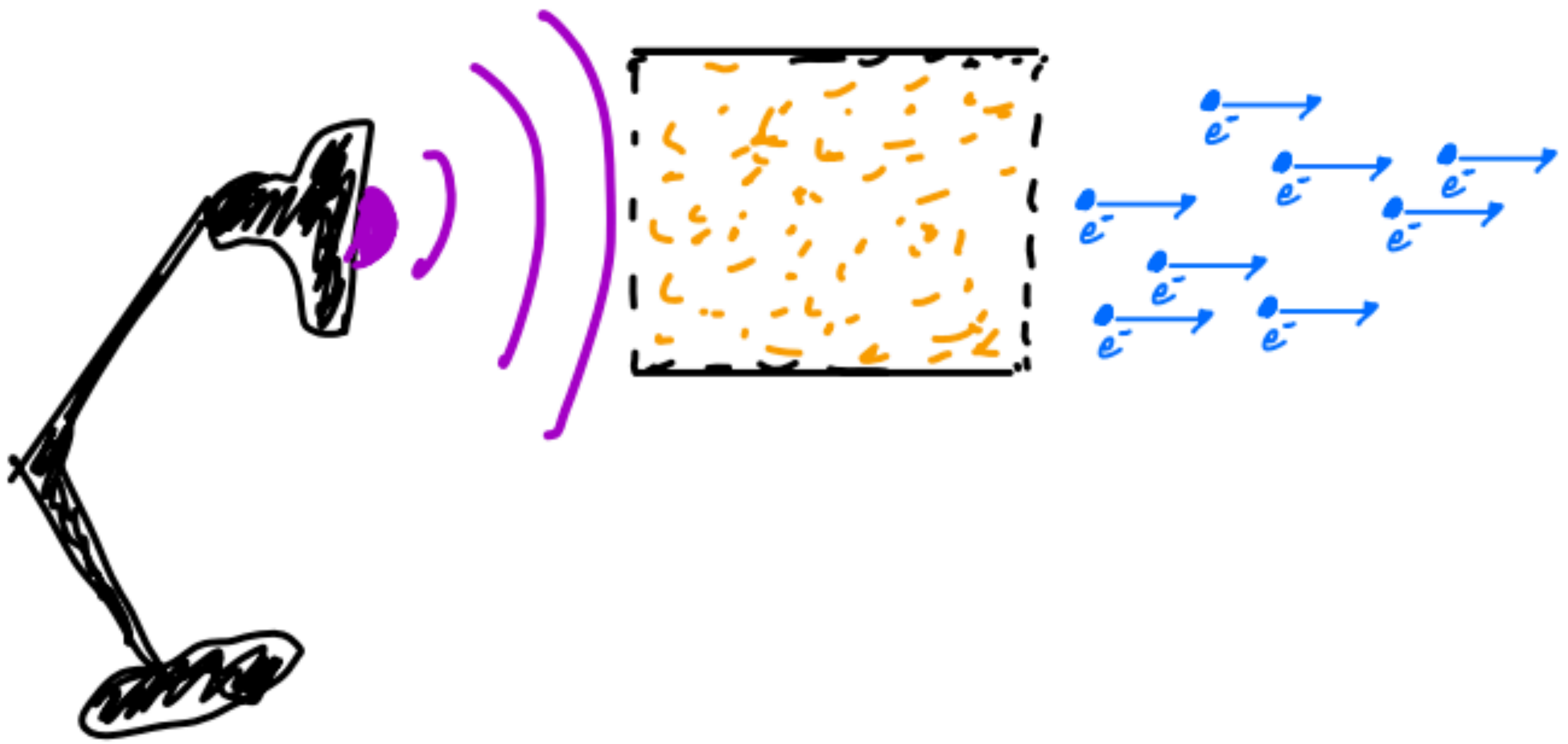
Planck's constant



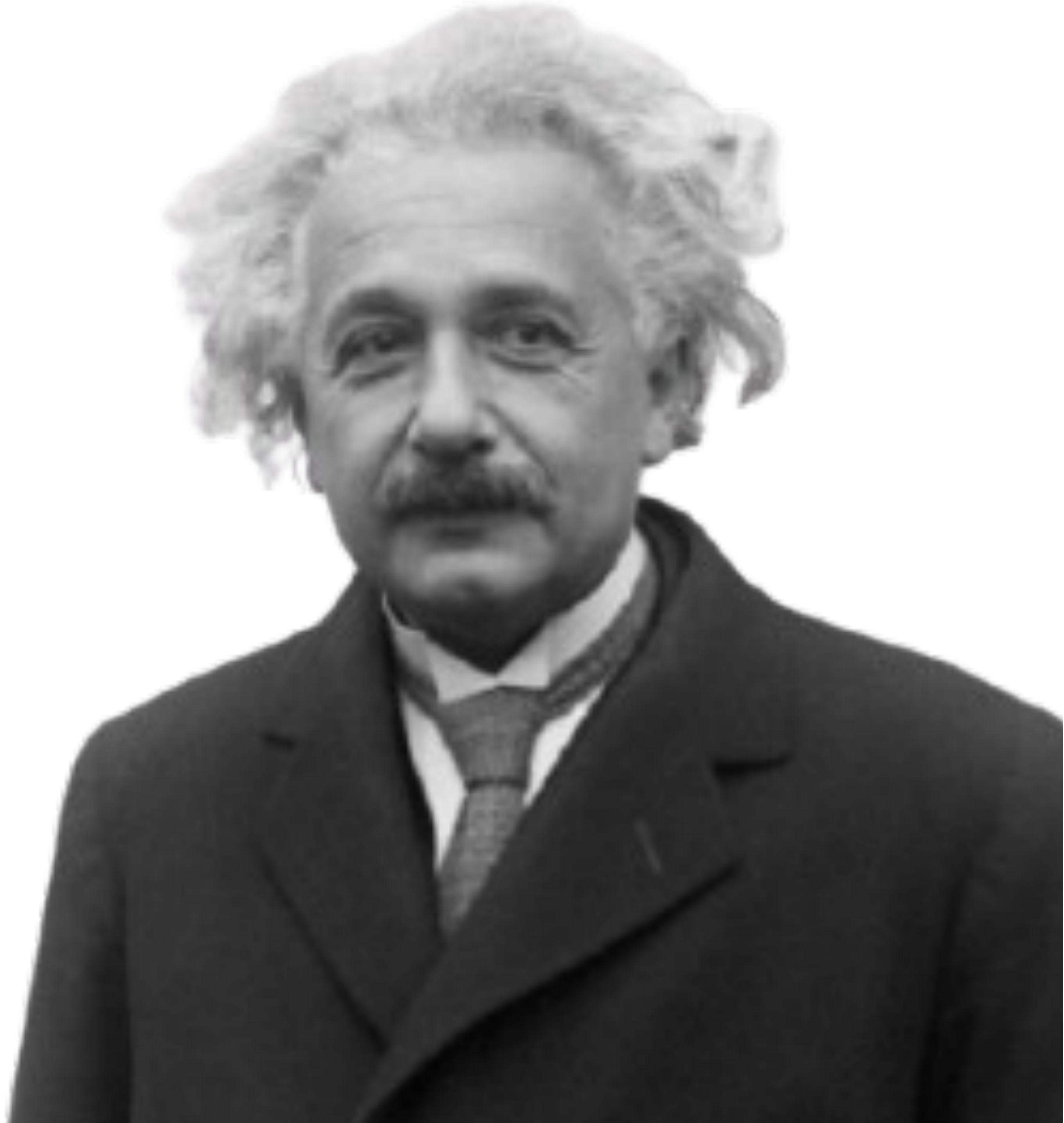
thermal radiation using classical theory with light emitted continuously

⇒ Does it mean light is quantized?

4) the photoelectric effect:



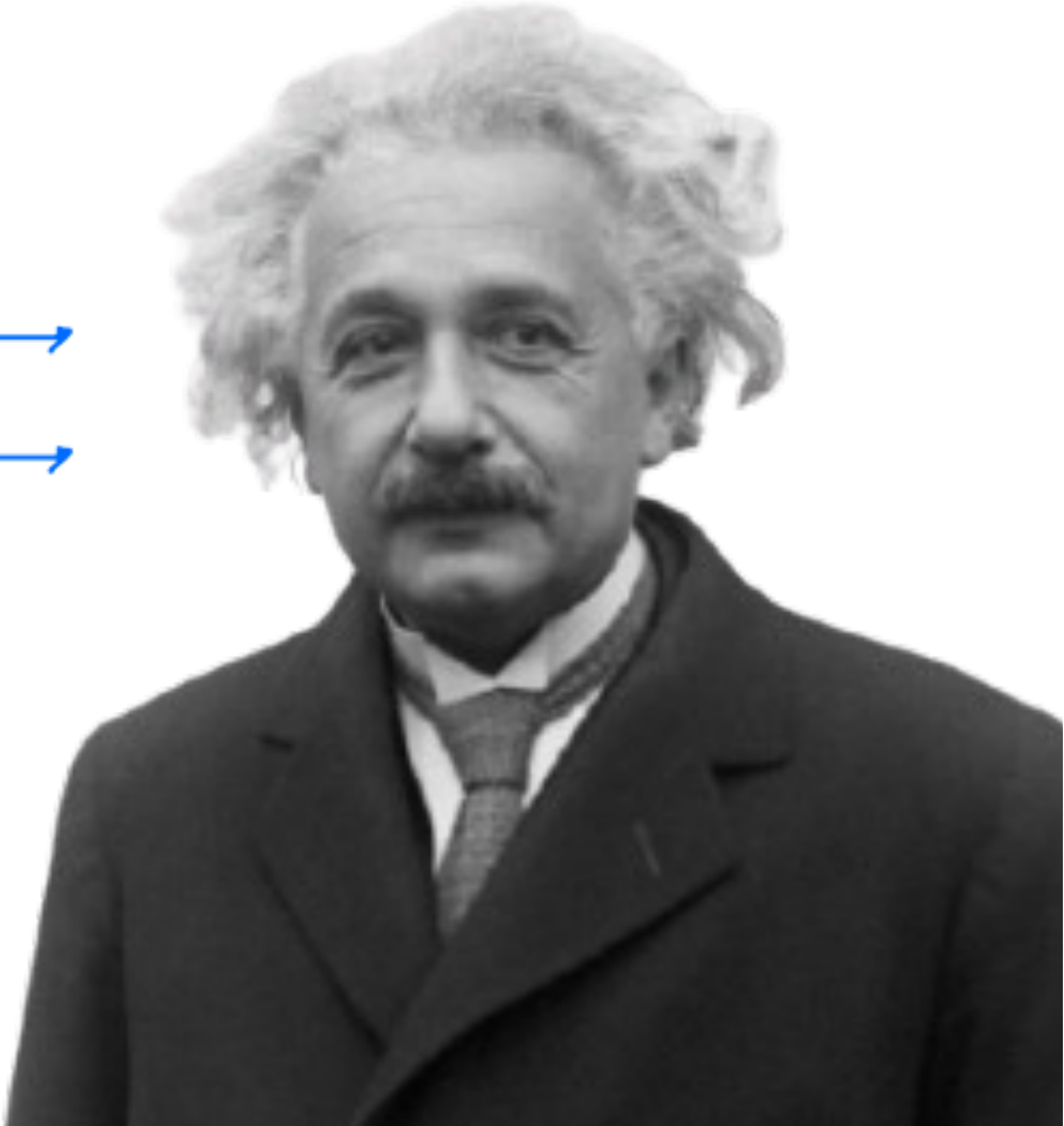
gas
ionization!



4) the photoelectric effect:

gas ionization!

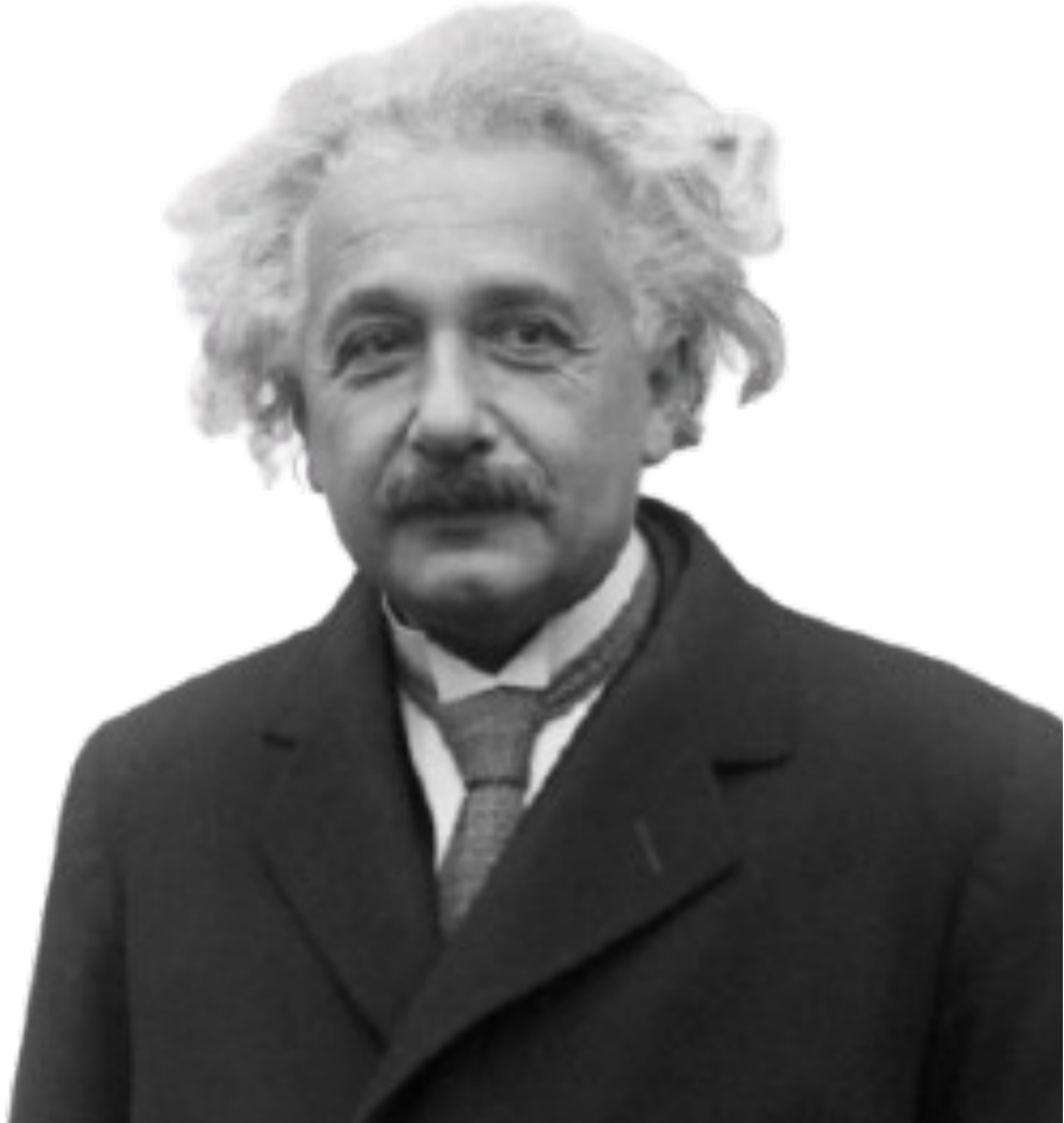
same frequency, less luminosity: electron's energy remains the same!



4) the photoelectric effect:

gas
ionization!

lower frequency, same luminosity: electron's are NOT excited!



4) the photoelectric effect:

gas
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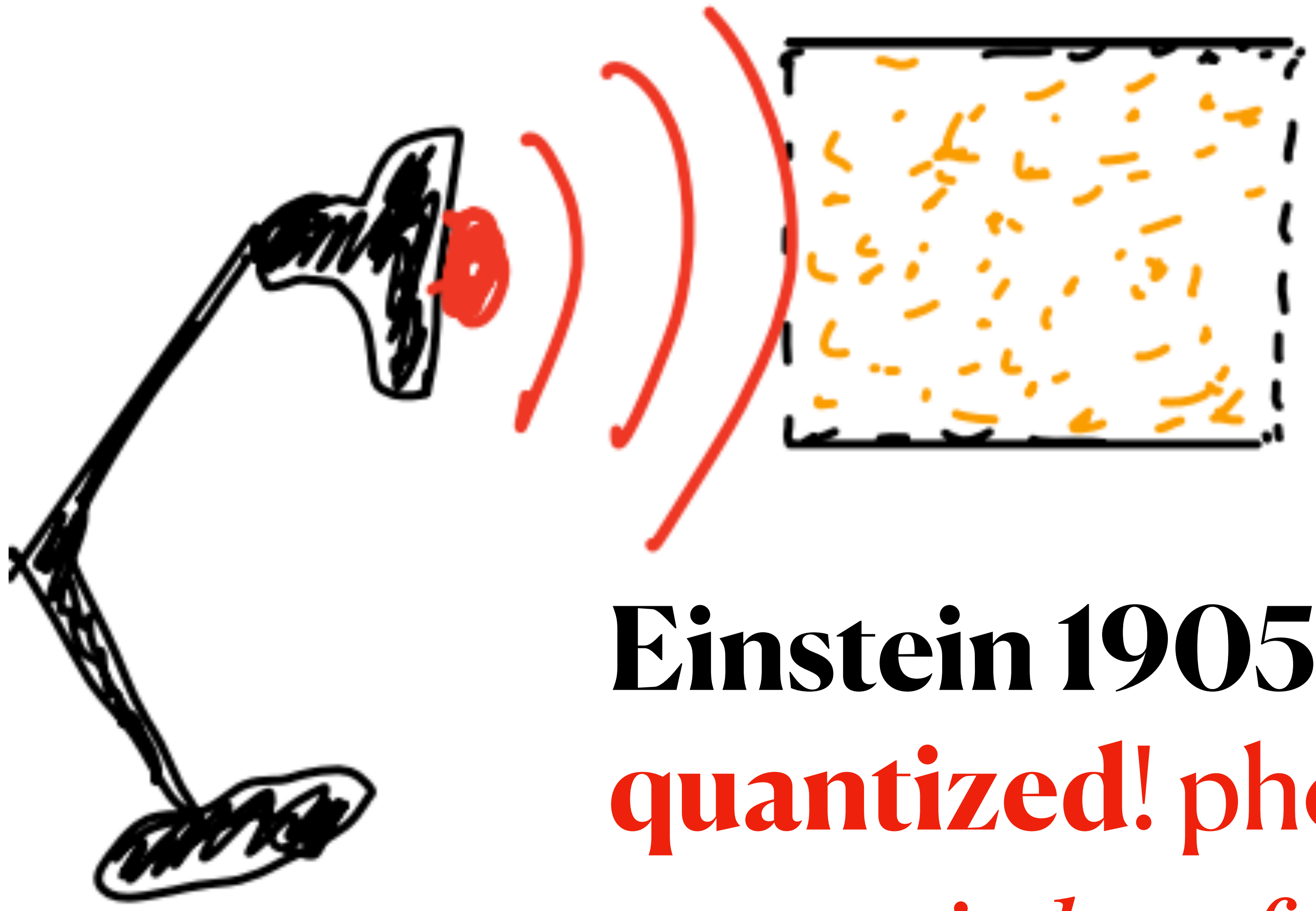
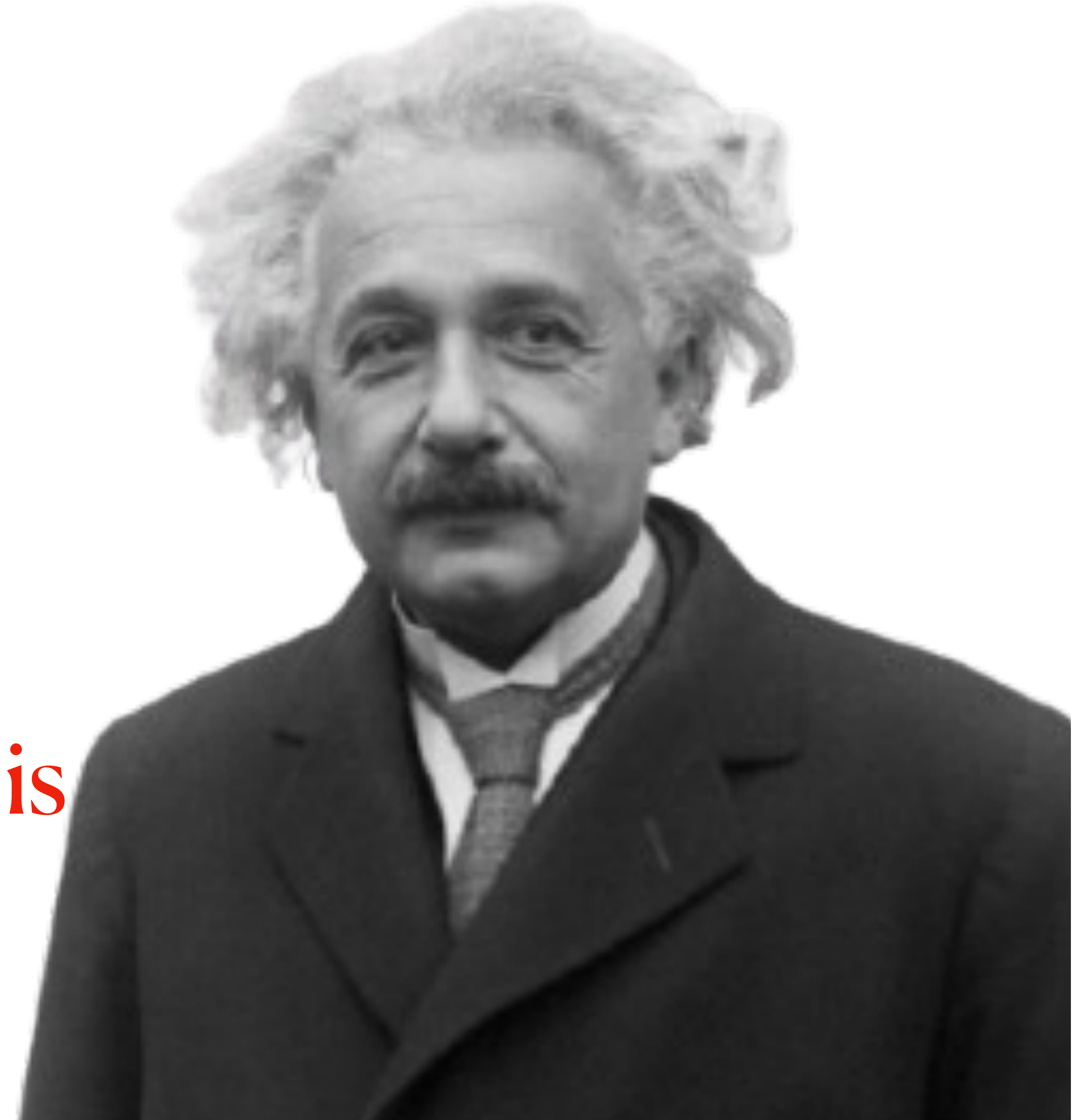


Einstein 1905: light is **quantized**! photon's energy is $h \times f$



Quantum Mechanics (1900s ~ 1925)

- light has wave and particle properties
- observations hint at discrete energy levels for atoms

Bohr:

- only discrete energy levels for electrons in an atom, then they cannot spiral into the nucleus!
- lowest energy level may be too large to be excited
- absorption may correspond to changing between allowed energy levels!

De Broglie:

- if electrons behave as waves, then discrete solutions in bound states as standing waves
- $\lambda = \frac{h}{p} \sim \frac{h}{mv}$, so very small particle-wavelength for big masses!

e.g.: $m = 1\ \mathrm{g}$, $\mathrm{v} \sim 1\ \mathrm{m/s} \Rightarrow \lambda \sim 10^{-91}\ \mathrm{m}$!

$\Rightarrow$ both radiation and matter have wave and particle properties!

Modern Quantum Mechanics

- Schrödinger equation: $\hat{H}\,\Psi(\vec{x},t) = i\hbar\frac{\partial}{\partial t}\Psi(\vec{x},t)$

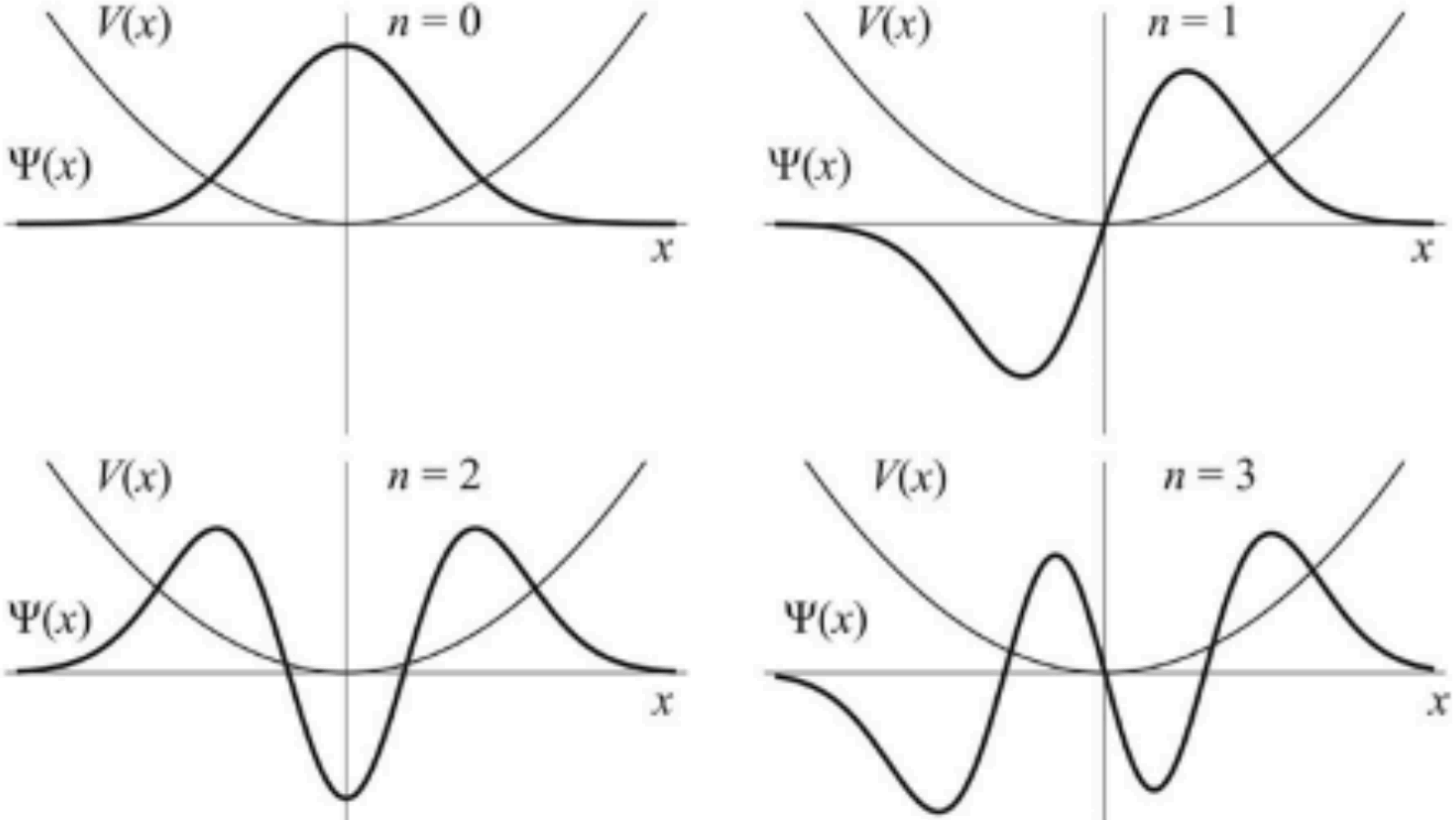
linear,
deterministic,
reversible!

- $|\Psi(\vec{x},t)|^2$: probability particle is at $\vec{x}$ at t when measured

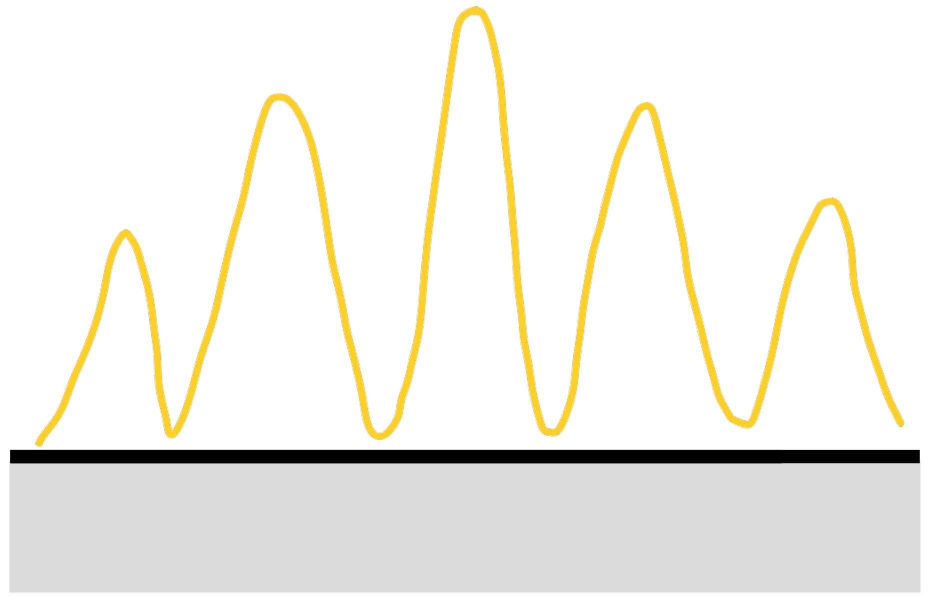
- rate of change of wavefunction depends on the energy
- nothing discrete about it, BUT:

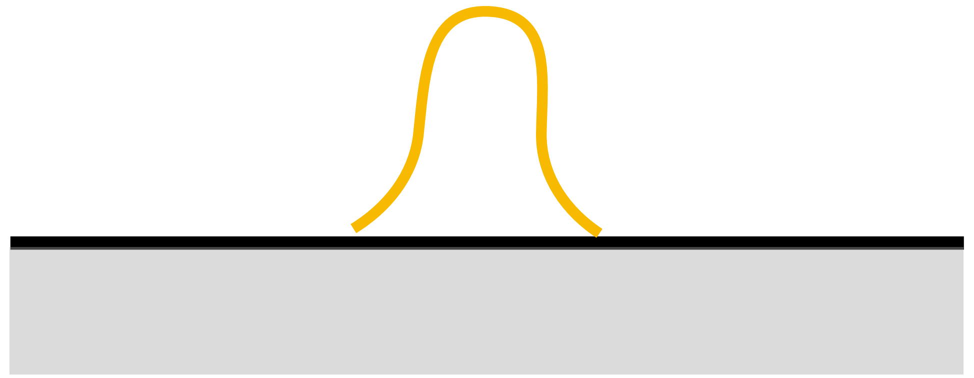
$$\hat{H} = \frac{\hat{p}^2}{2m} + V(\vec{x})$$

same with electrons trapped by the Coulomb potential inside an atom! Not the case for a free particle!



Measurement: Do **NOT** seem to follow Schrödinger equation!





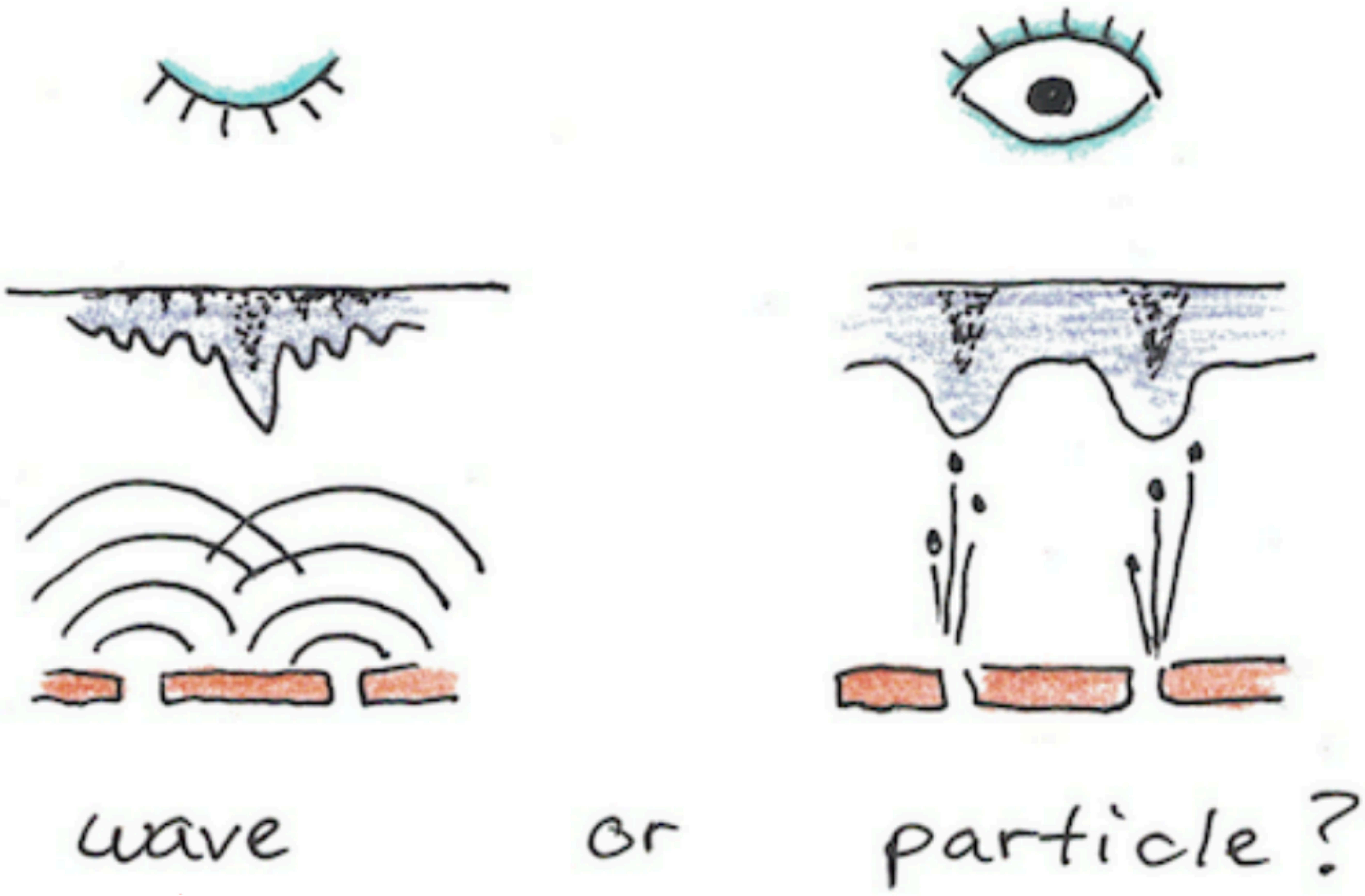
"collapse" -

irreversible, instantaneous, non-deterministic

No analogue in classical mechanics:
can always make measurement
effect arbitrarily small!

$$|\Psi_1\rangle = \frac{1}{\sqrt{2}}|\mathrm{LEFT}\rangle + \frac{1}{\sqrt{2}}|\mathrm{RIGHT}\rangle \longrightarrow |\Psi_1(t_f)\rangle = |\mathrm{RIGHT}\rangle$$

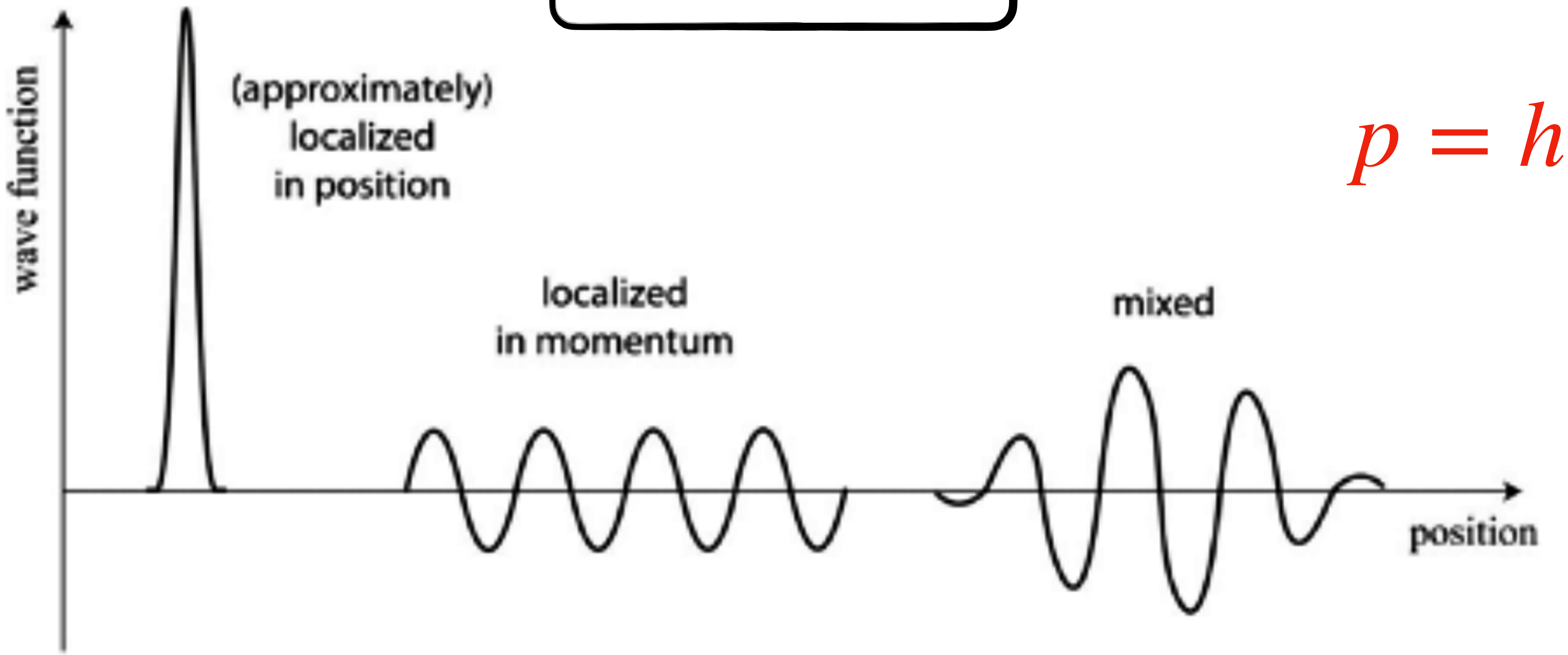
$$|\Psi_2\rangle = 0.999999\,|\mathrm{LEFT}\rangle + 0.000001\,|\mathrm{RIGHT}\rangle \longrightarrow |\Psi_2(t_f)\rangle = |\mathrm{RIGHT}\rangle$$



(superposition/indefiniteness) (position/definiteness)

The Uncertainty Principle

$$\boxed{\Delta x \Delta p \leq \frac{\hbar}{2}}$$



$$p = h \times \lambda$$

Intrinsic to the quantum state: it's NOT that when we measure, we "bump" onto the particle. No state where both position and momentum are localized

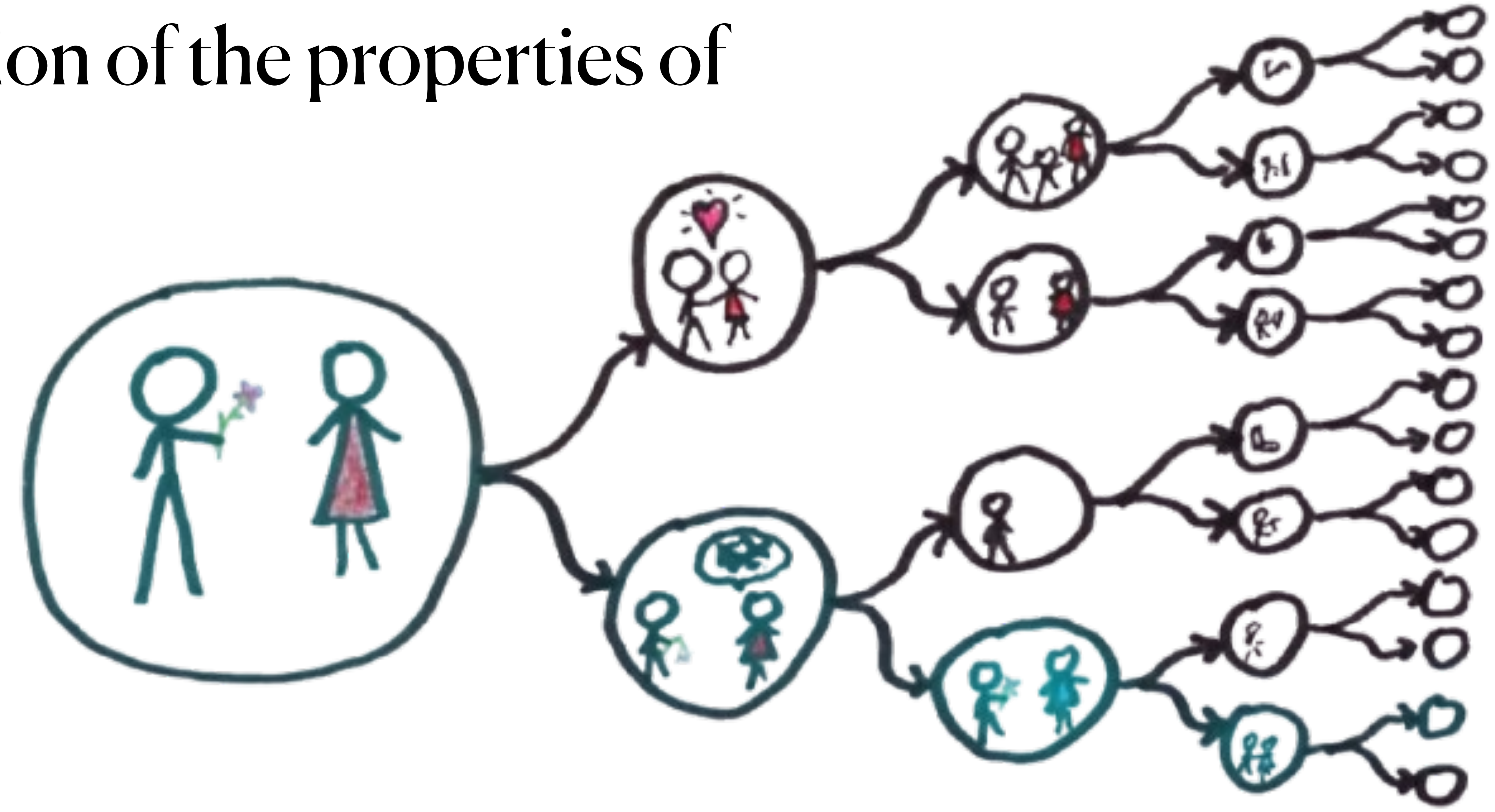
$\Rightarrow$ no independent definite existence!

The Measurement and Reality Problems

- What's a measurement? How quickly does the wavefunction collapse? Do we need conscious agents?

- It seems to change the probability distribution of the properties of objects $\Rightarrow$ change of physical state **BUT**

  - Instantaneous to preserve probabilities
  - Not to do with energy/information to respect special relativity!



- But does it represent reality then? Or a book-keeping tool?

- It's natural to associate reality with what we observe (old and good positivism!), thus superposition puts in check $\Psi(x, t)$ reality or what reality is!

Why does any of this matter?