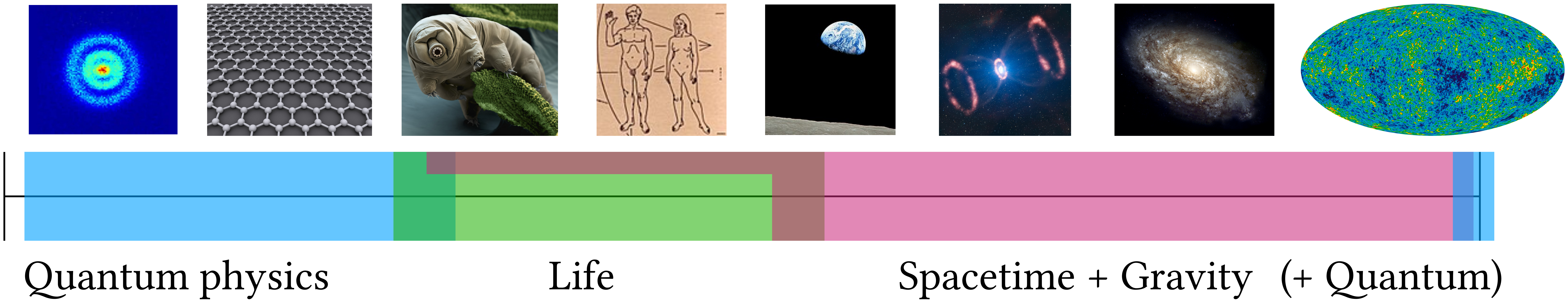
Quantumness

what it is

and isn't

Gramounce lecture—27.01.25
Abel Jansma
@Abelaer

Physics at different scales



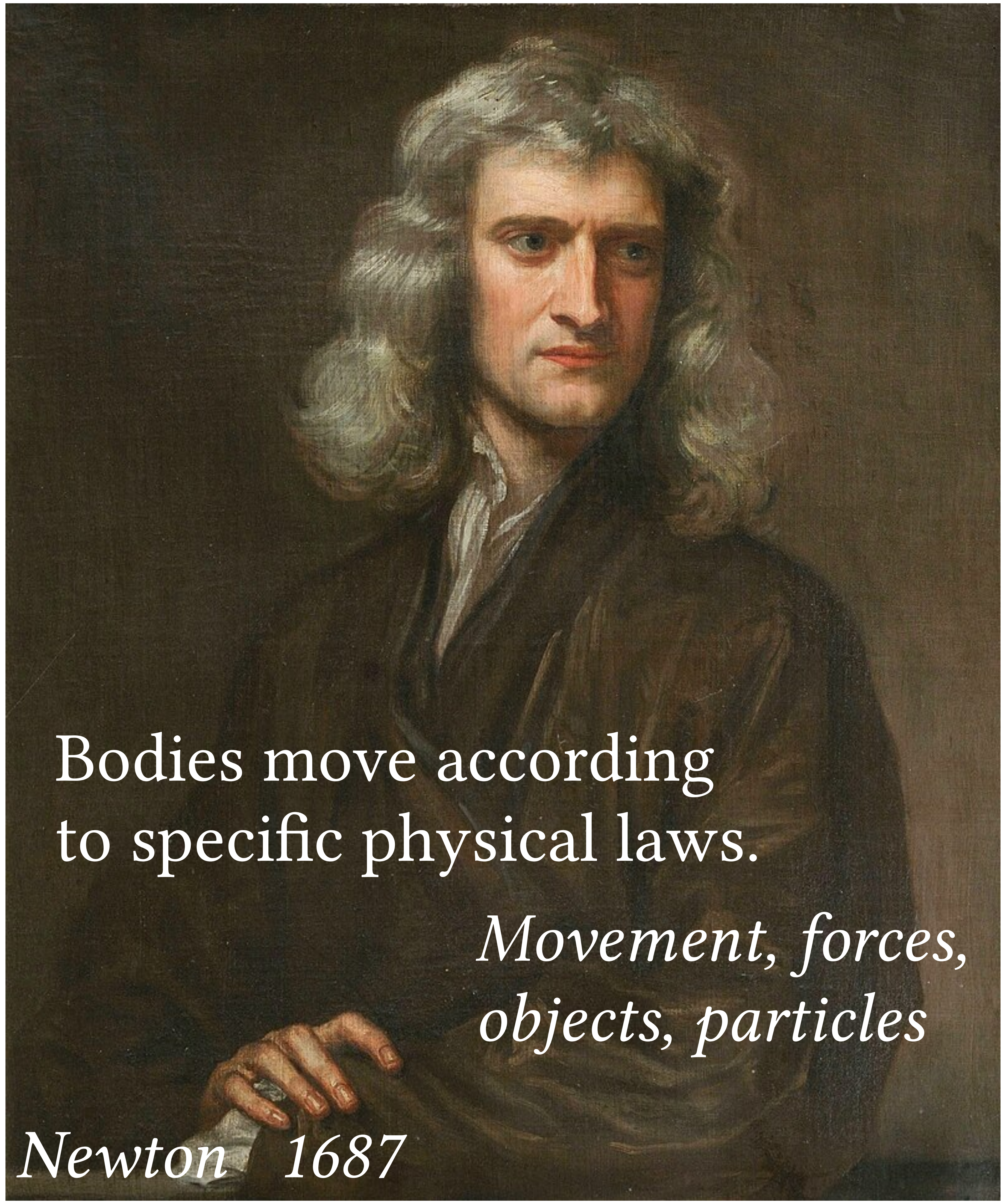
Overview

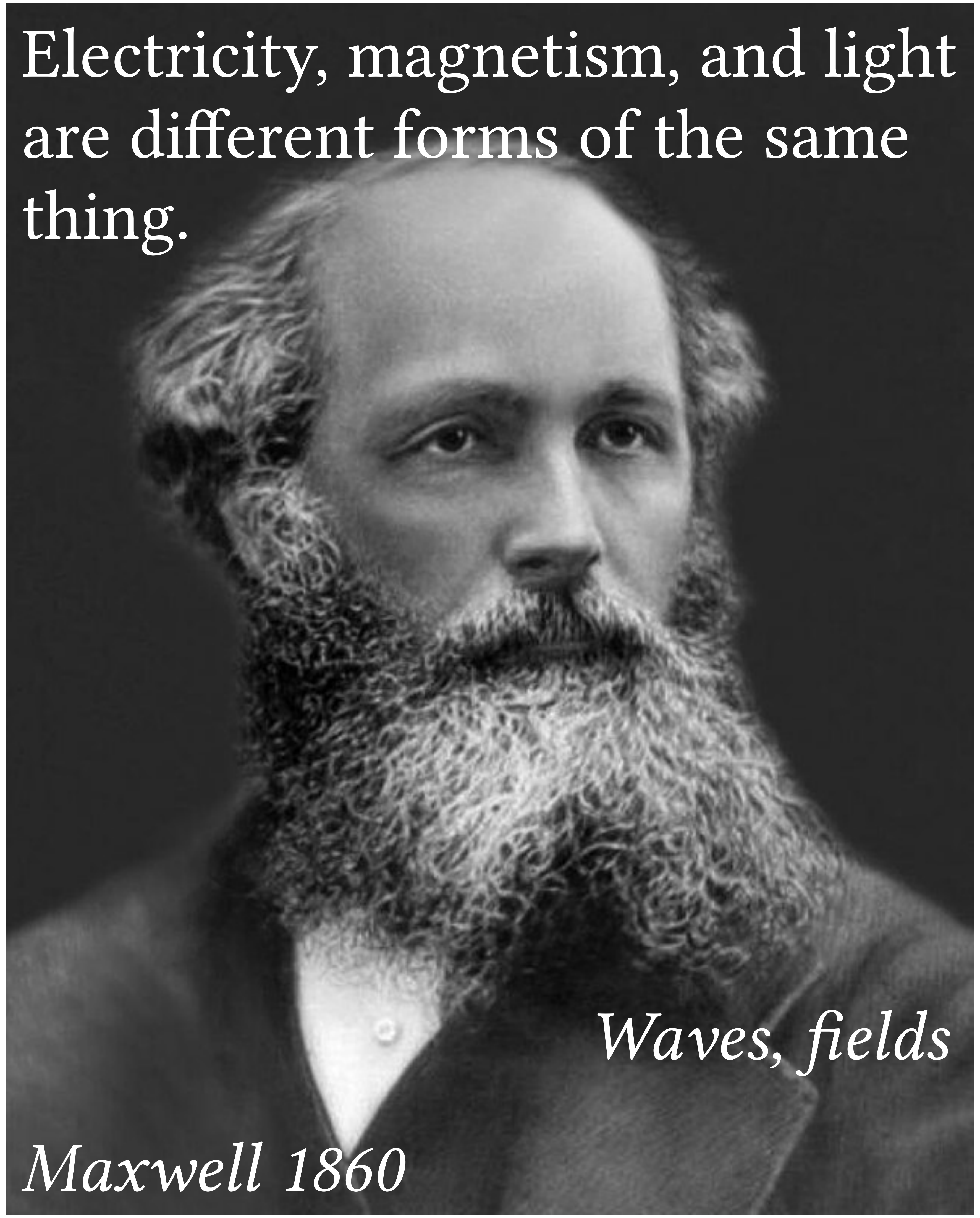
- History of Quantumness
- What does Quantum theory say?
- The Weirdness

Takeaway

- What it isn't: vagueness, everything-allowedness
- What is is: extremely precise, deterministically uncertain, weirder than you can (probably) imagine

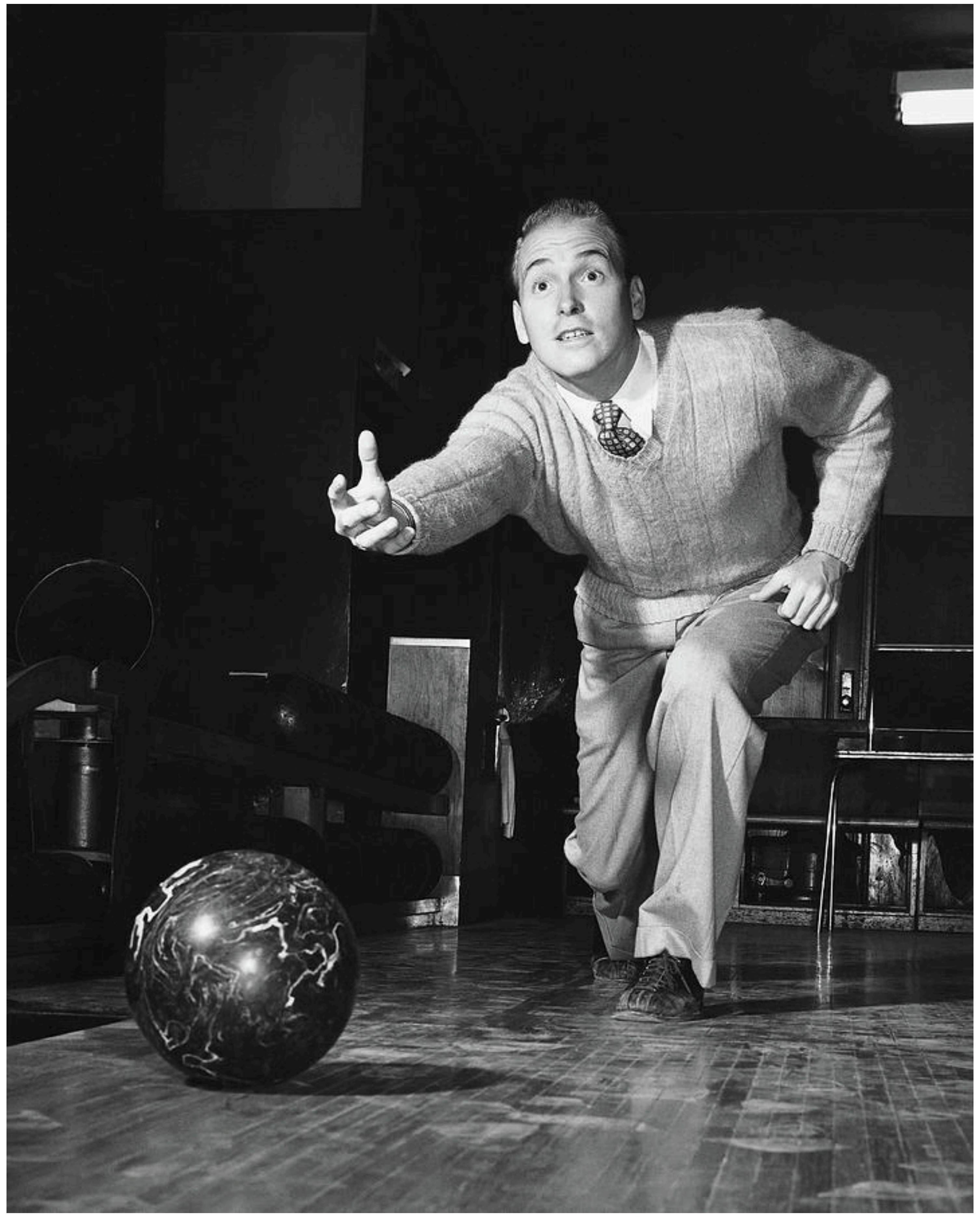
“Classical” Physics





Classical states

State: (position, velocity)

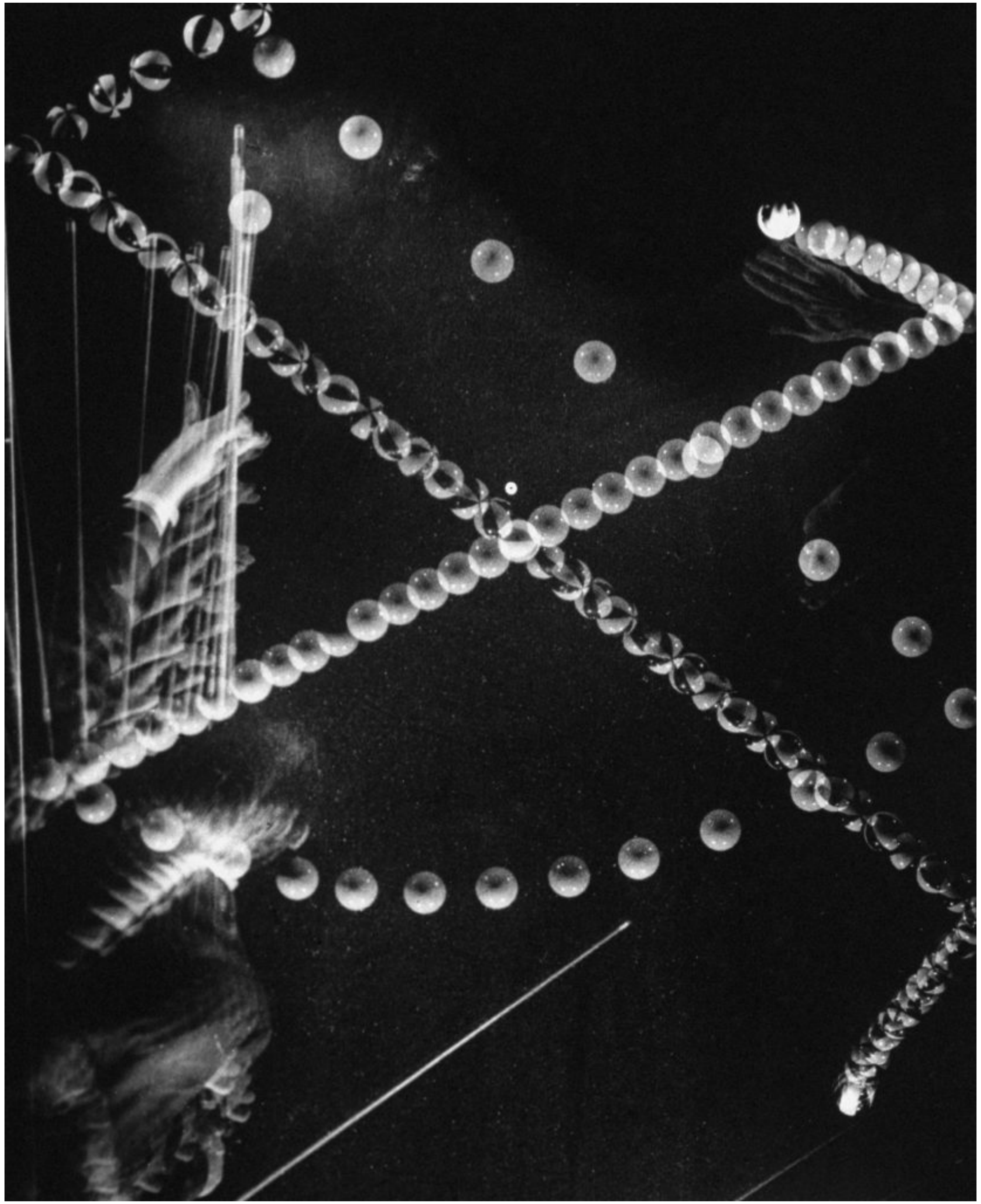


(position, velocity, spin)

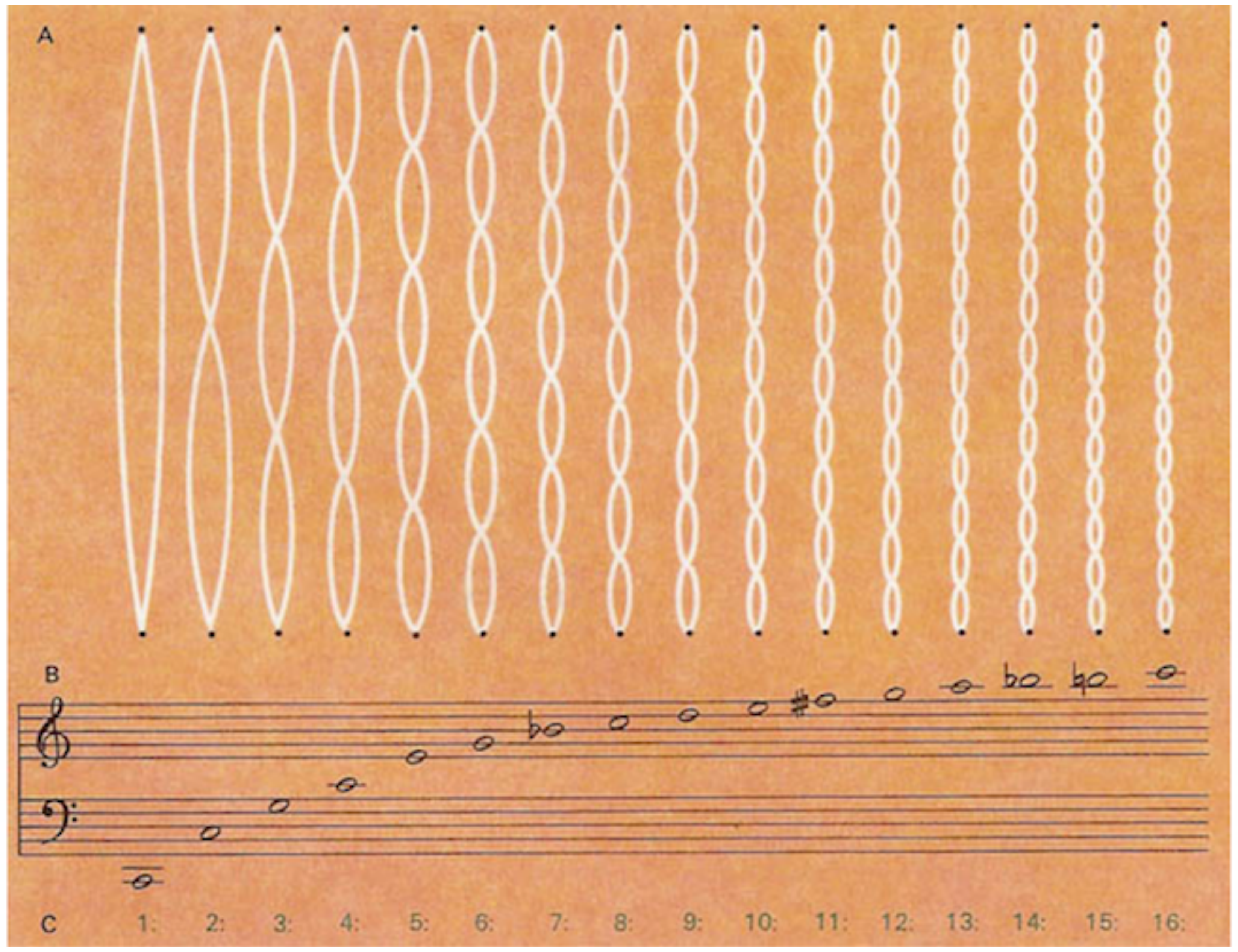
(temperature, cooking time, al-dente)

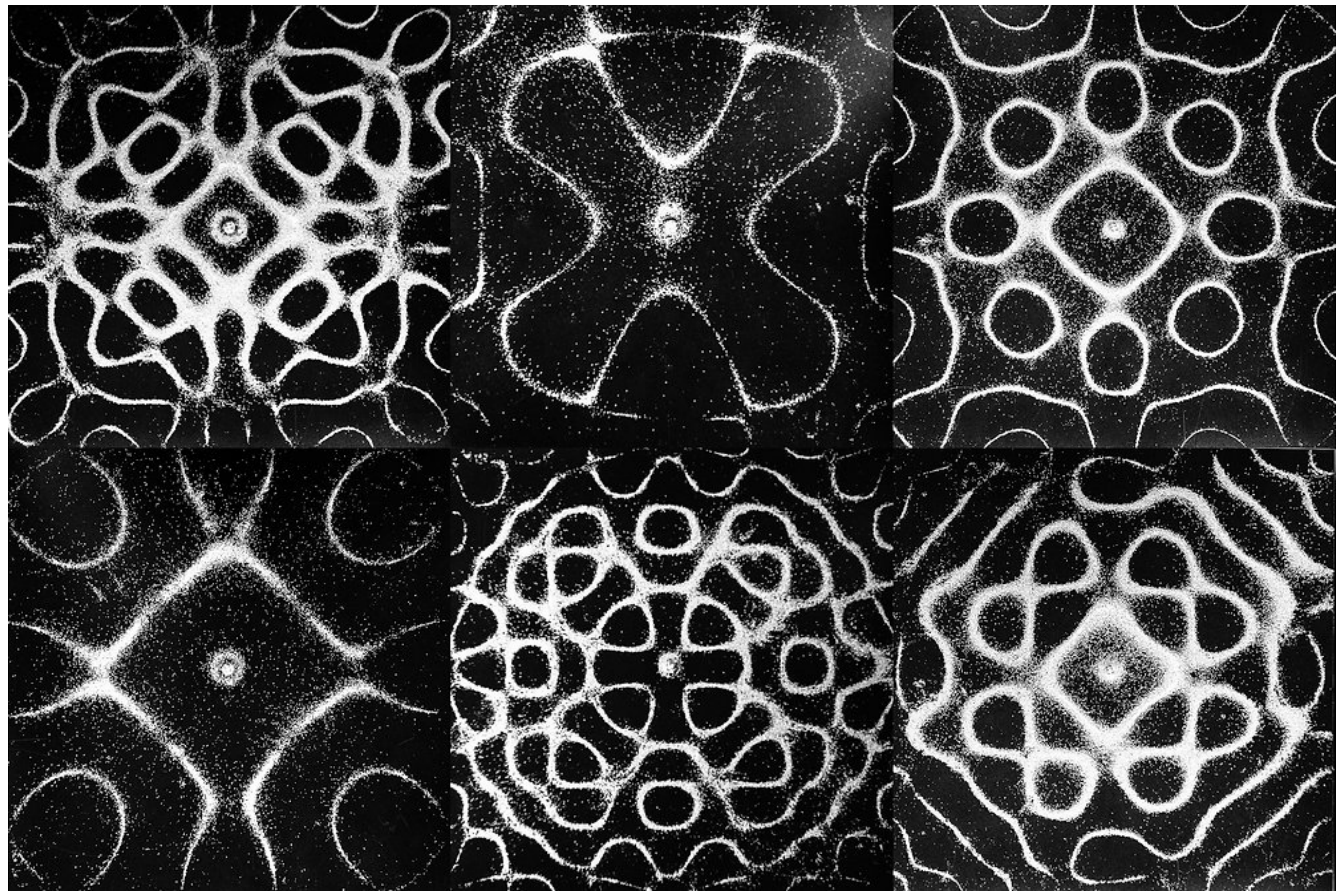
State Now

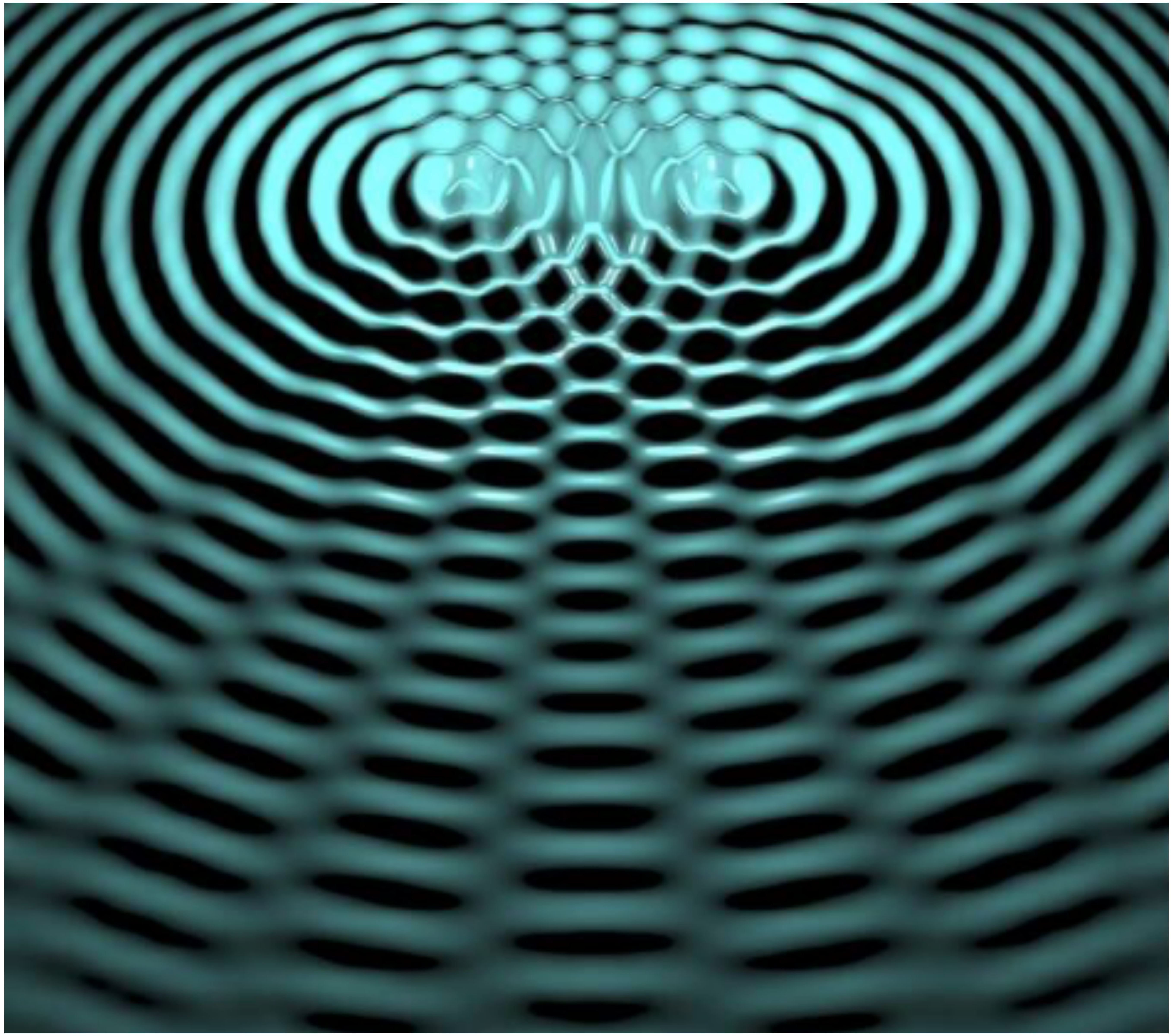
State Future



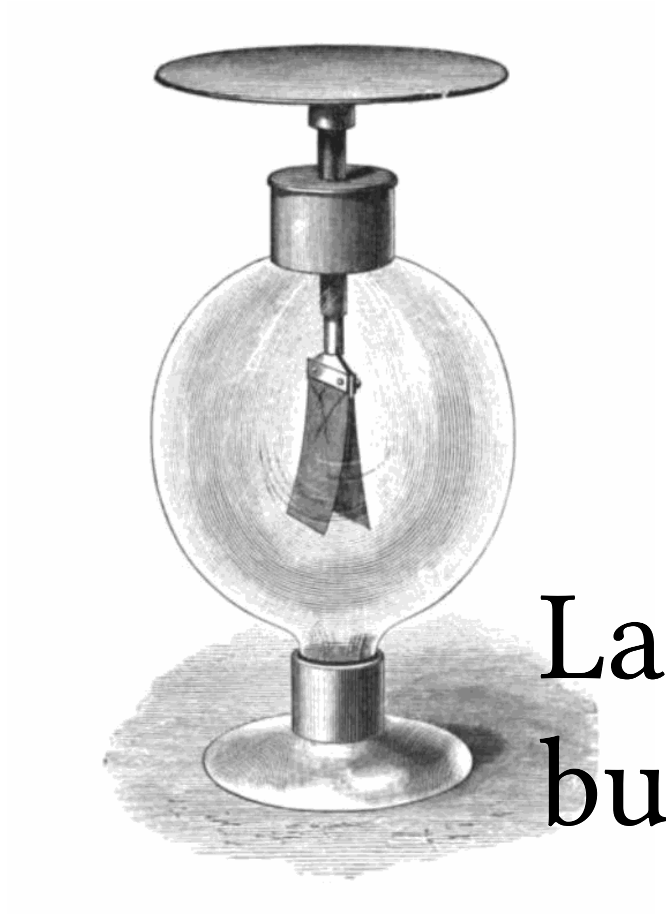
Waves



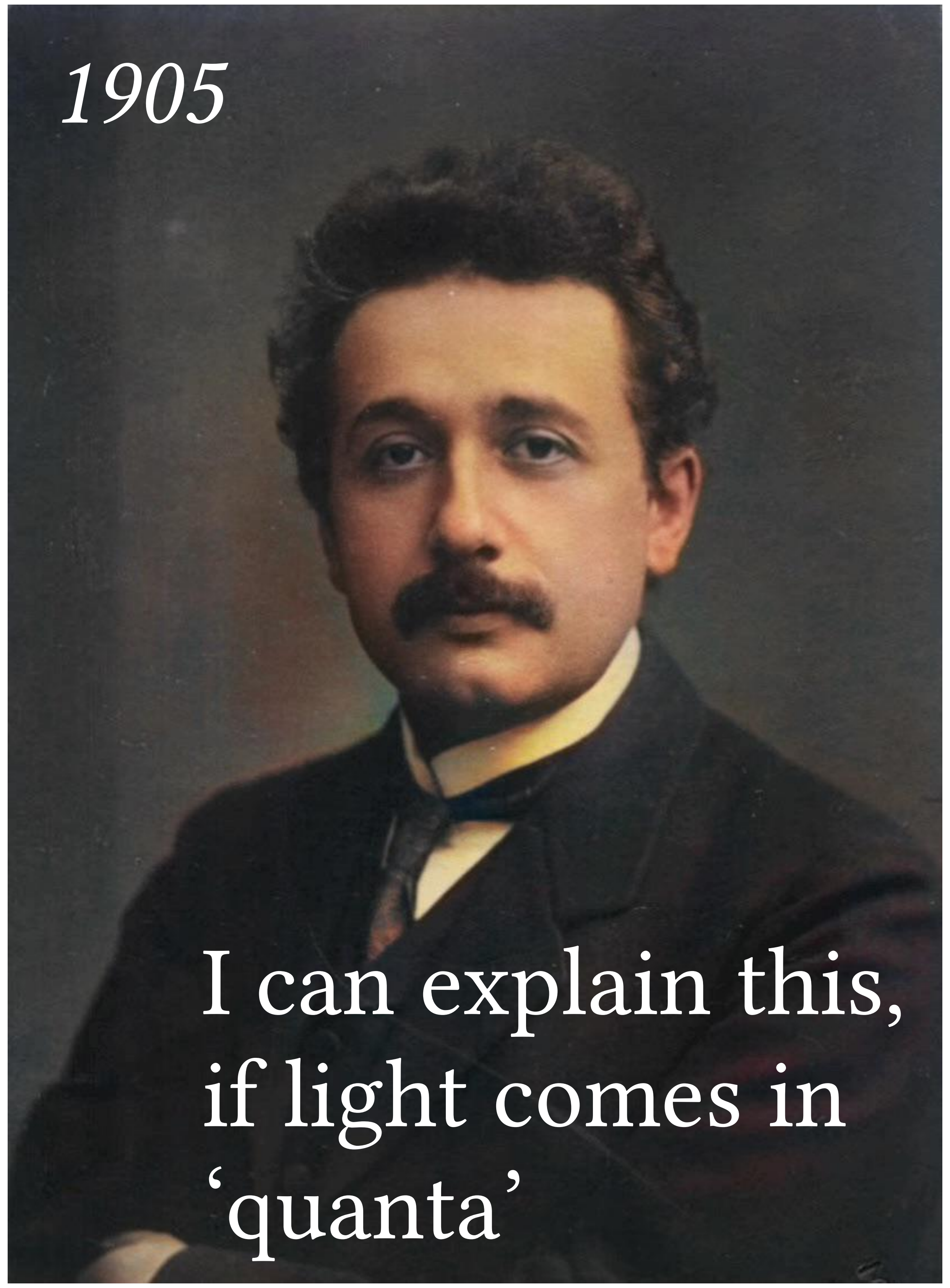




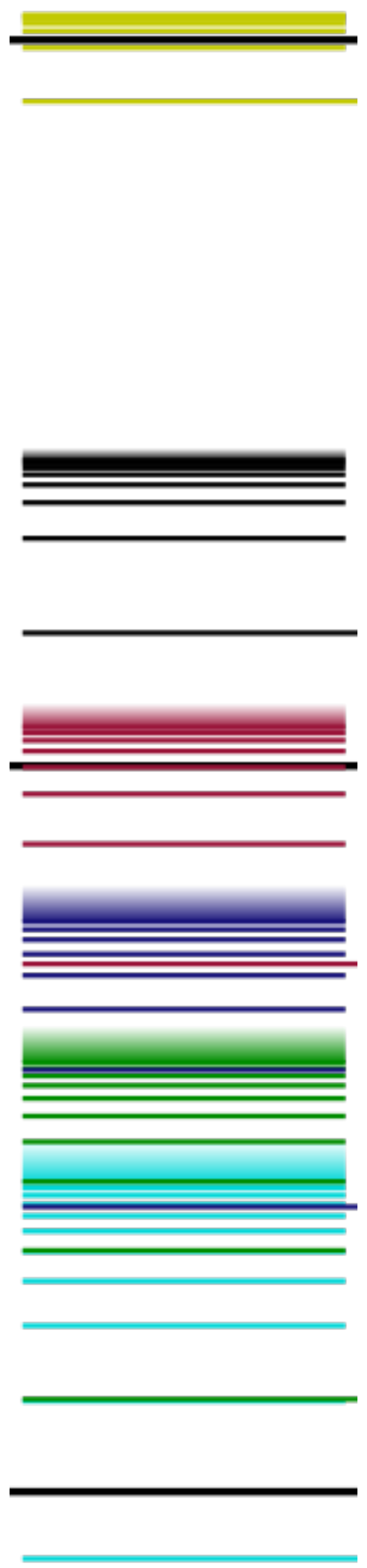
Physics is done, but...

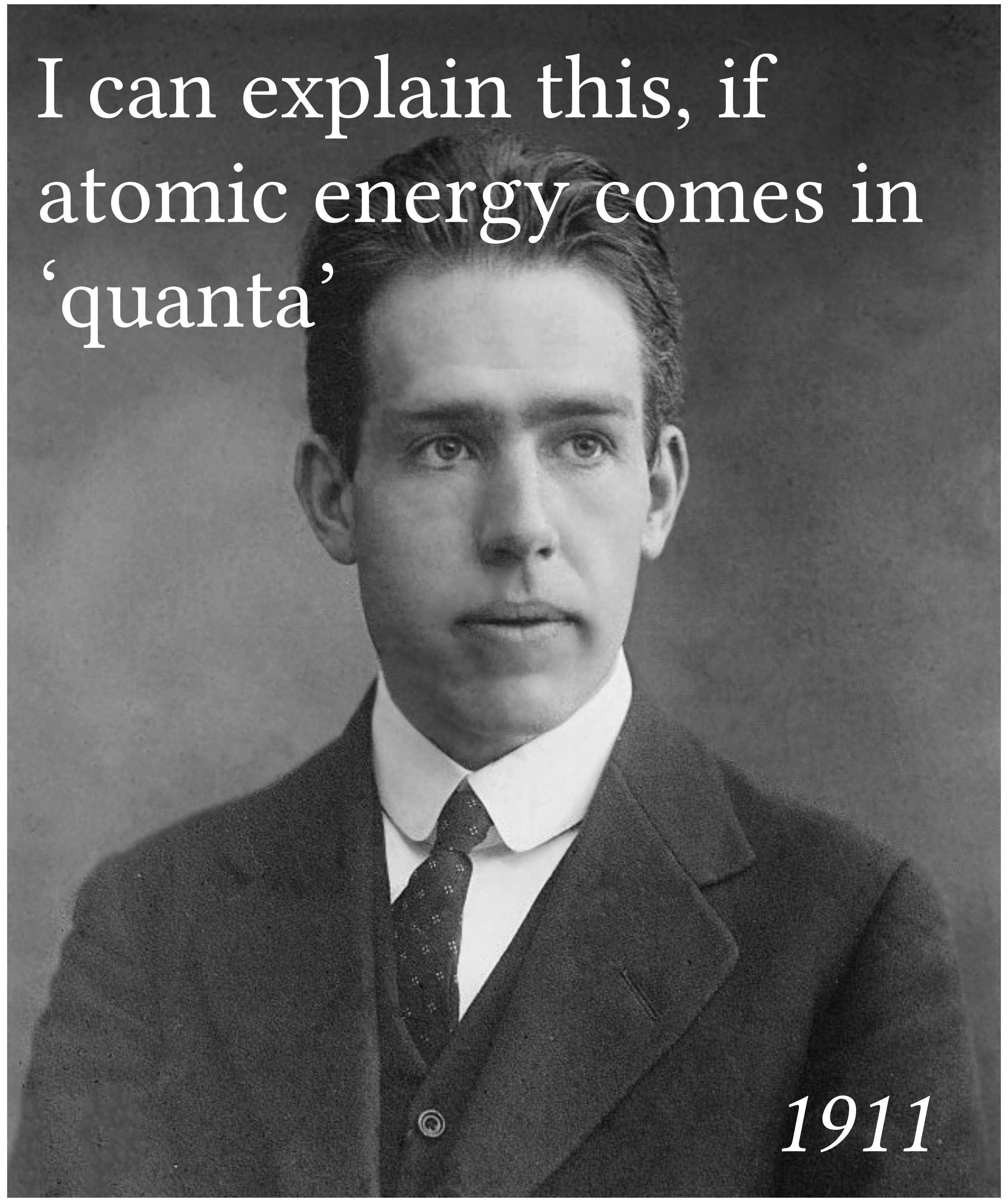


Launch particles with light—
but only in specific colours?



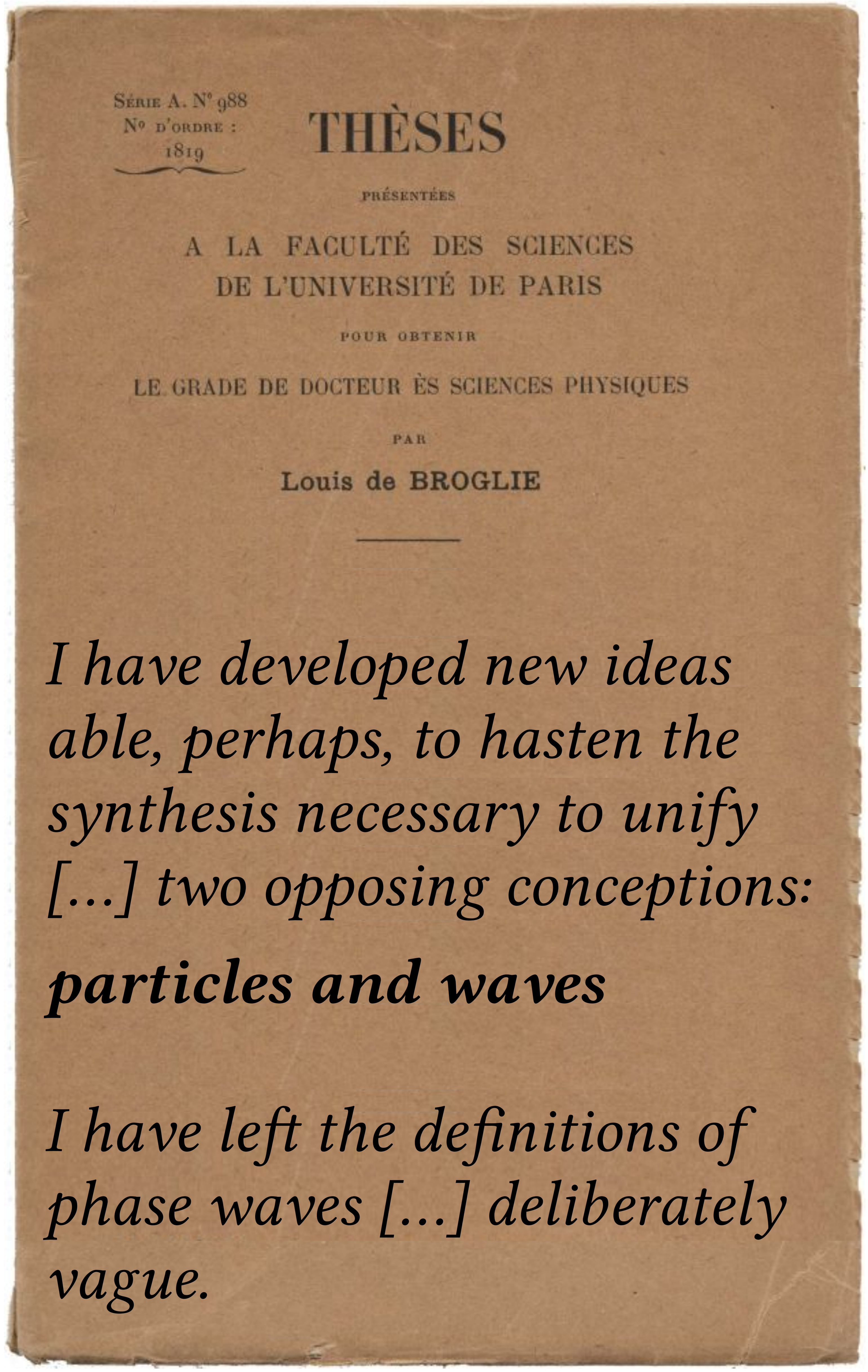
Hot gas glows—
but only in specific colours?





Matter waves back

After long reflection in solitude and meditation, I suddenly had the idea…



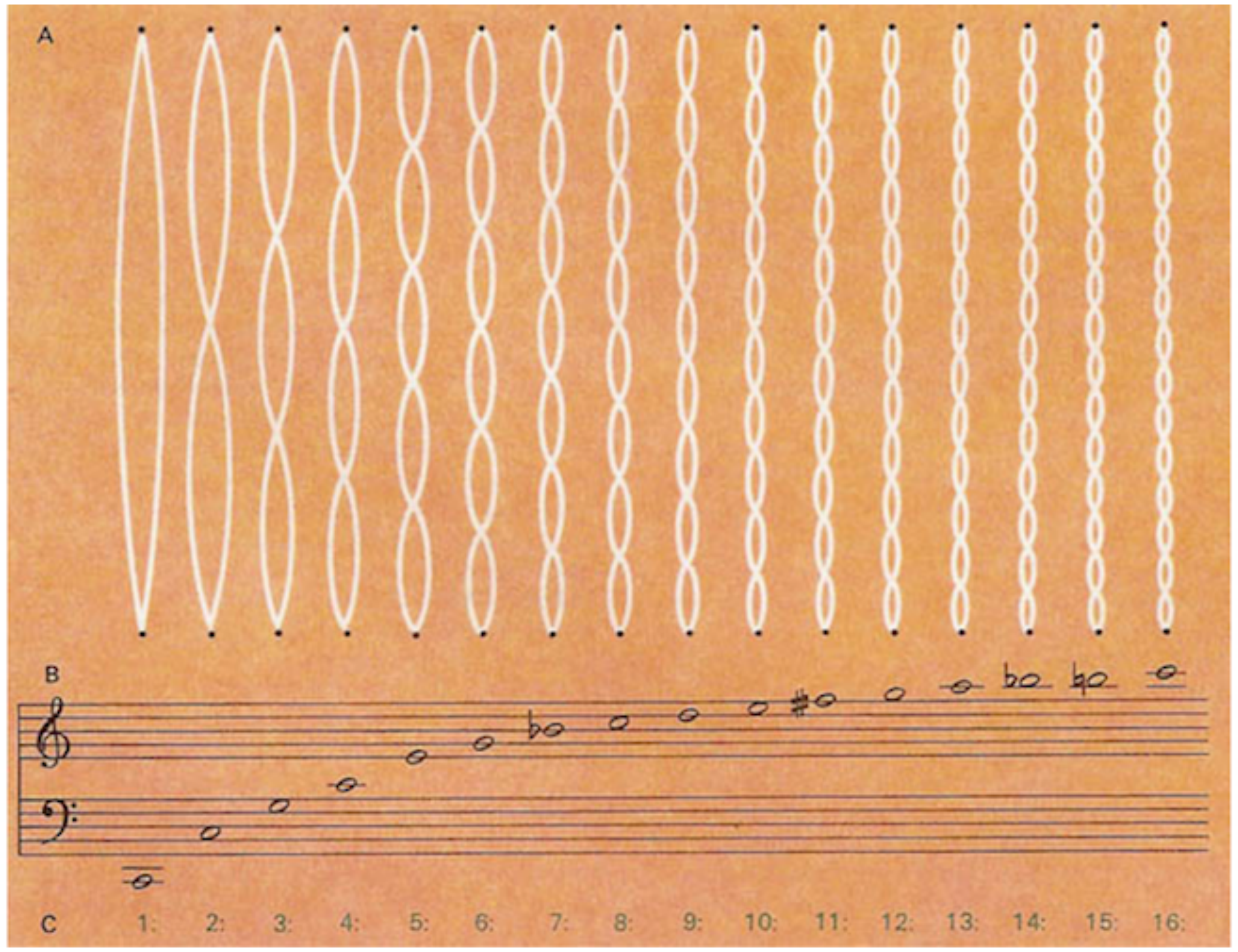
I have developed new ideas able, perhaps, to hasten the synthesis necessary to unify […] two opposing conceptions:

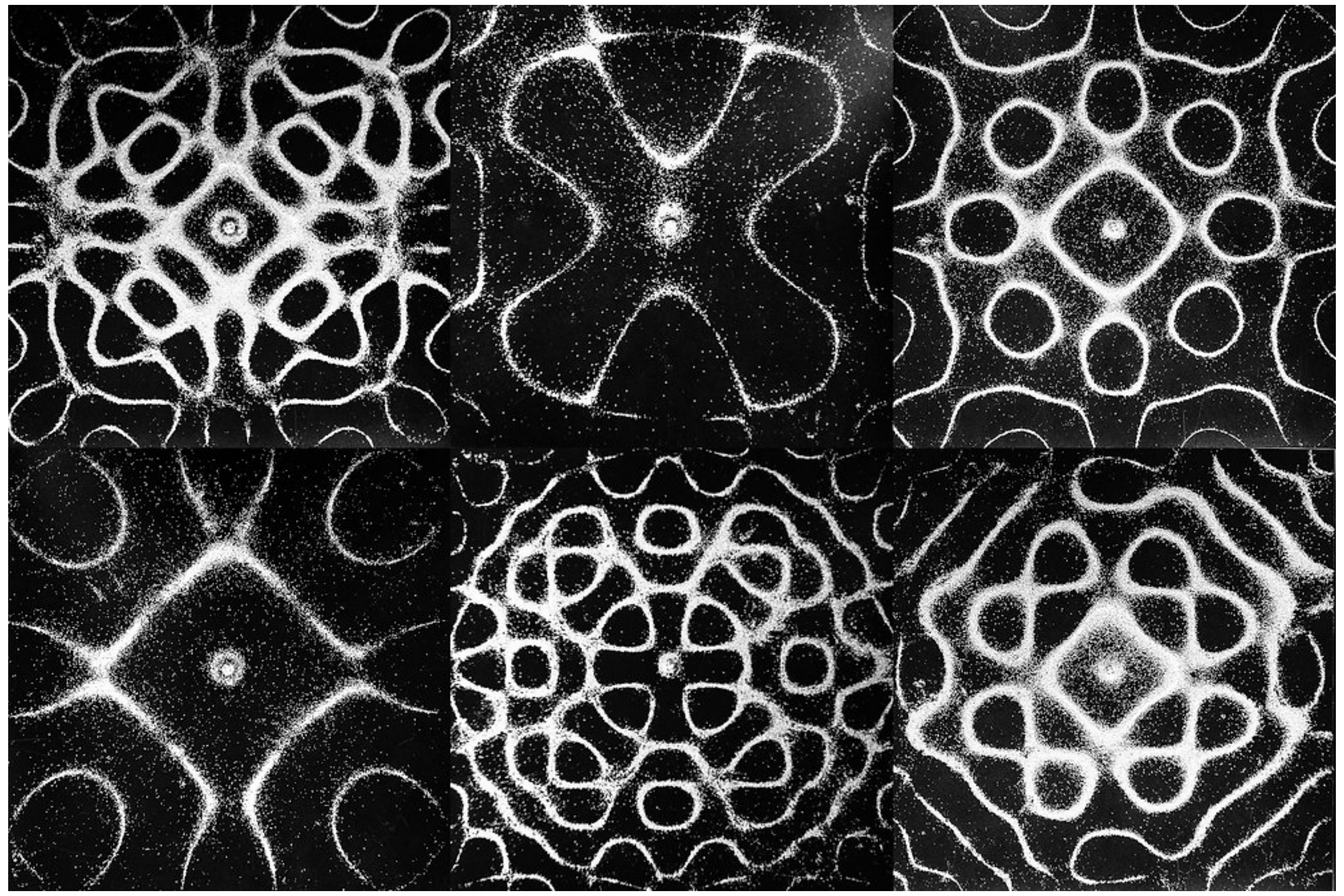
particles and waves

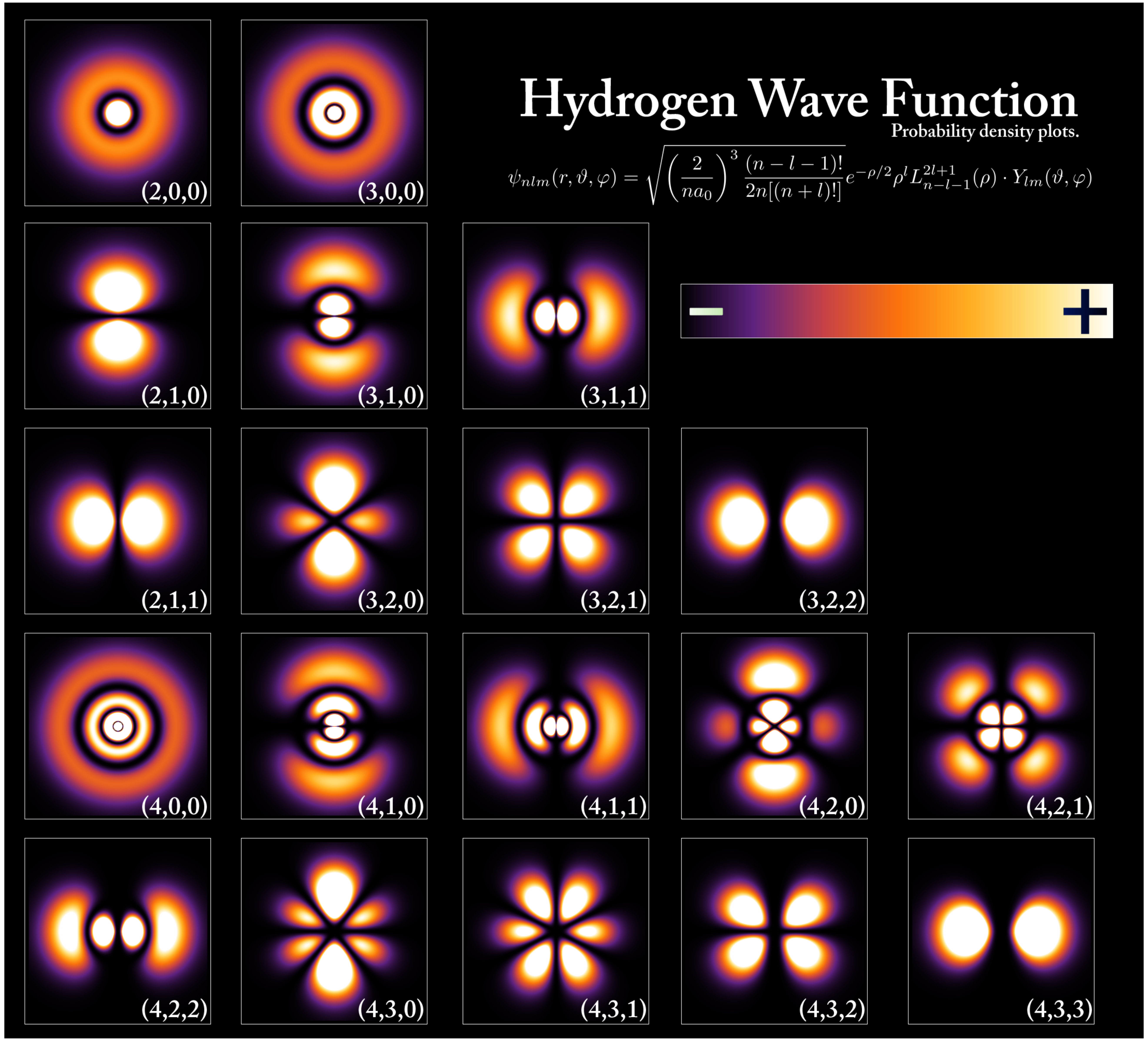
I have left the definitions of phase waves […] deliberately vague.

Classical waves

Quantum waves








A BOY AND
HIS ATOM

Schrödinger Equation

$$i\hbar\frac{\partial}{\partial t}|\psi\rangle = \hat{H}|\psi\rangle$$

Matter changes in time, as a wave, by a certain amount determined by its energy

$i = \sqrt{-1}$

$\hbar = 0.00000000000000000000000000000000000155 \; J \cdot s$

Quantum states

$$\color{orange}{i}\color{green}{\hbar}\color{blue}{\frac{\partial}{\partial t}}|\psi\rangle = \color{magenta}{\hat{H}}|\psi\rangle$$

$|\psi\rangle$ Now →  → $|\psi\rangle$ Future

"Superpositions" are also a valid state!

$$|\text{ball}\rangle = 0.50|\text{on table}\rangle + 0.87|\text{on floor}\rangle$$

$$|\text{cat}\rangle = 0.45|\text{dead}\rangle + 0.89|\text{alive}\rangle$$

"What do you mean by that?" said the Caterpillar sternly. "Explain yourself!"

"I can't explain *myself*, I'm afraid, sir," said Alice, "because I'm not myself, you see."

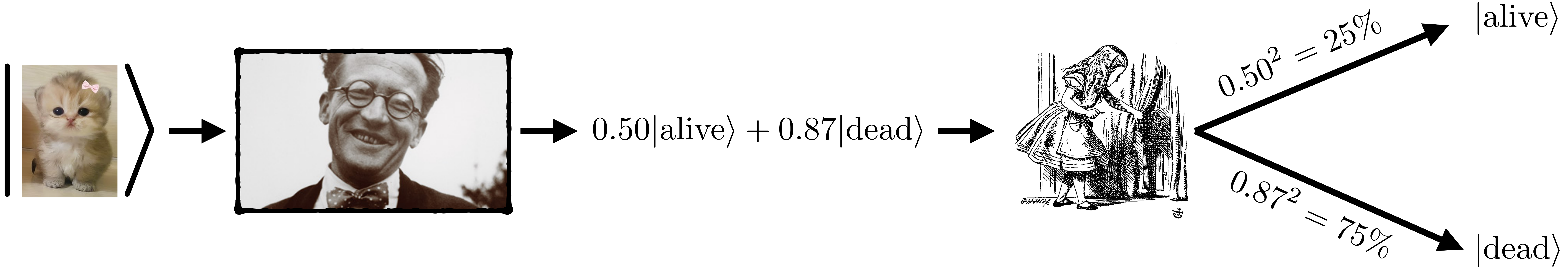
"I don't see," said the Caterpillar.

"I'm afraid I can't put it more clearly," Alice replied very politely, "for I can't understand it myself to begin with;

Physicists: Things are in a complex superposition.

Normal people: But I don't *see* superpositions!

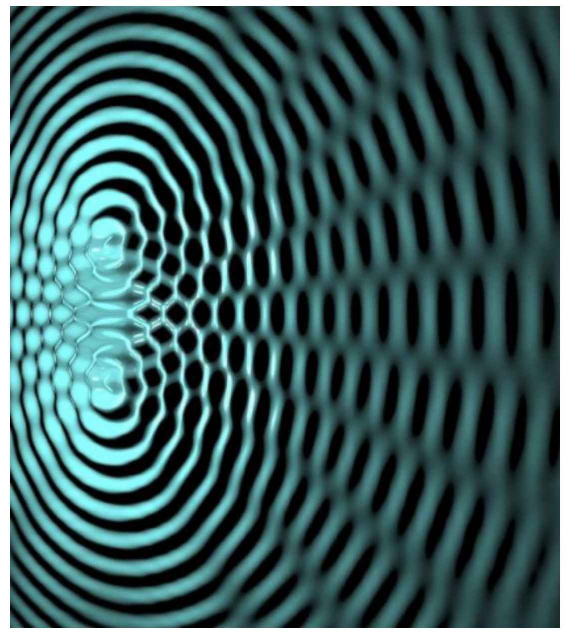
Physicists: Ah ok but when you look, the state collapses!

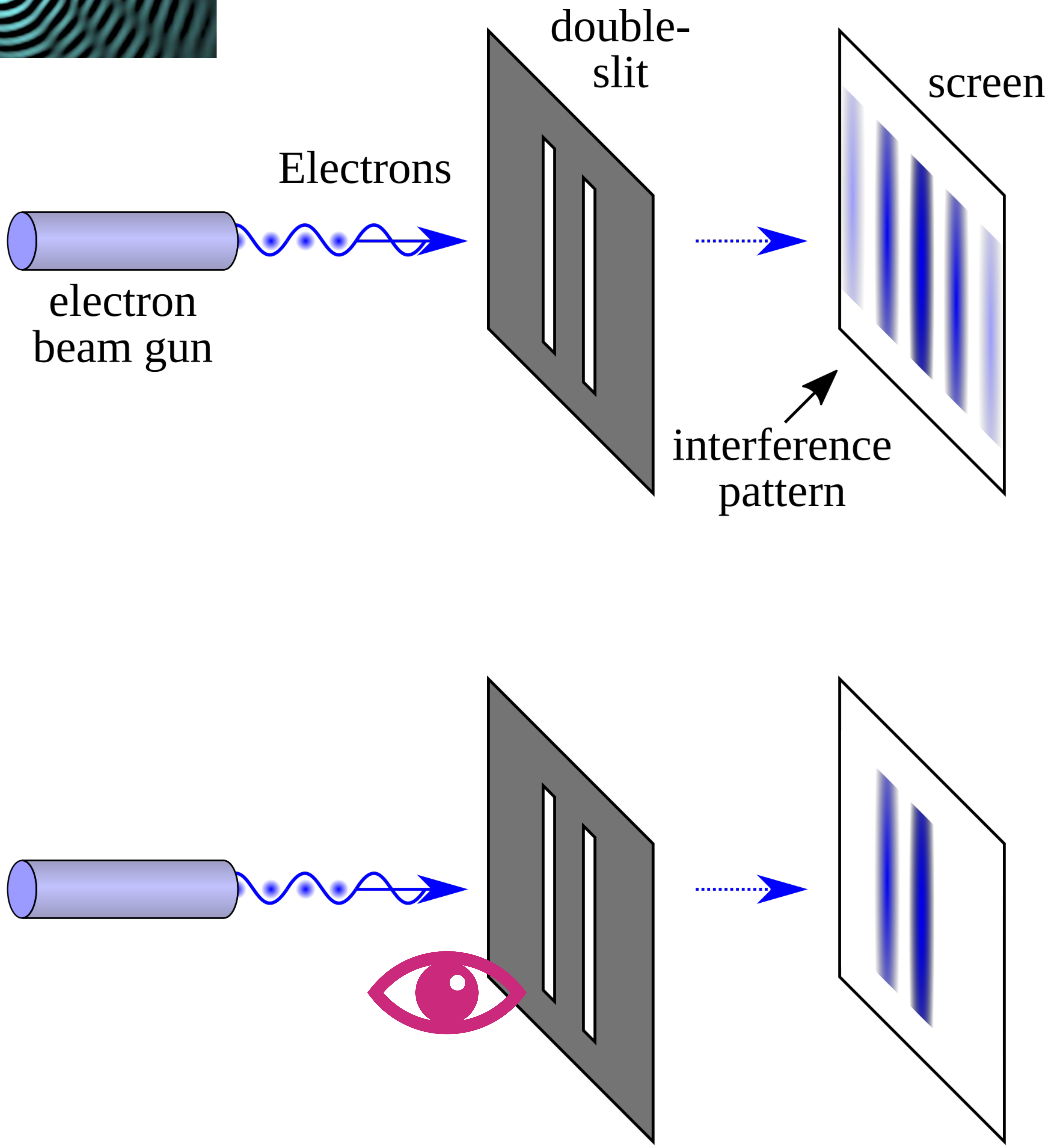


Deterministic

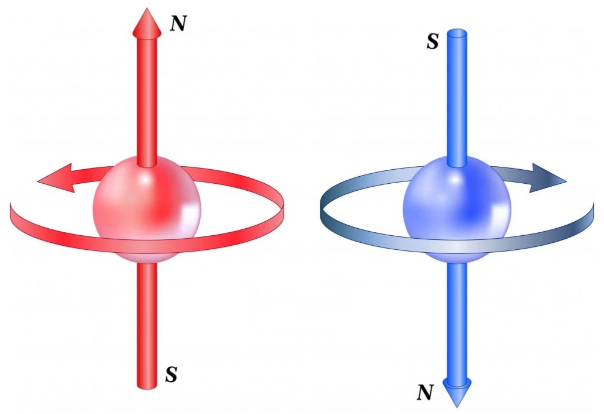
Uncertainty

Wavefunction "collapse"

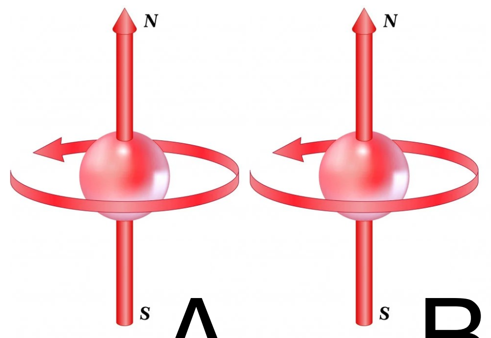
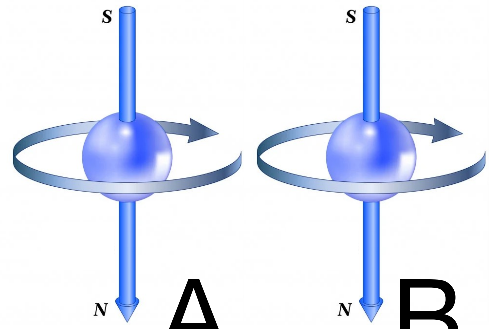




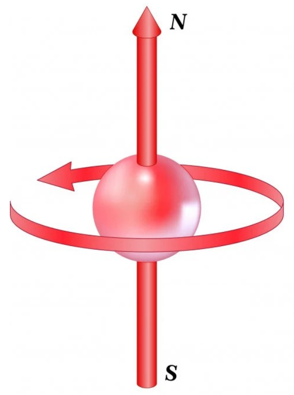
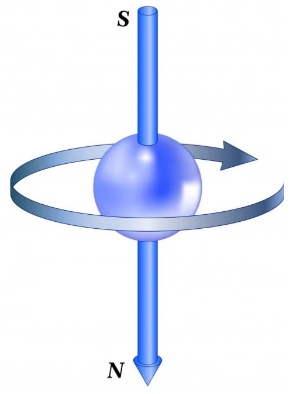
Entanglement—*Spooky action at a distance*

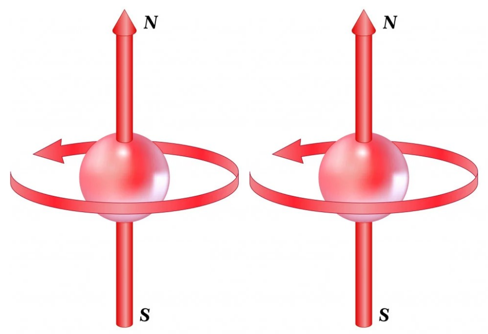
Electrons spin points ‘up’ or ‘down’: 

Alice and Bob both have ‘twin’ electrons:

$|\psi\rangle = 0.7\,\big|$  $\big\rangle + 0.7\,\big|$  $\big\rangle$

Alice’s electron state is a *relationship*, not a fact. The two *cannot* be described separately.

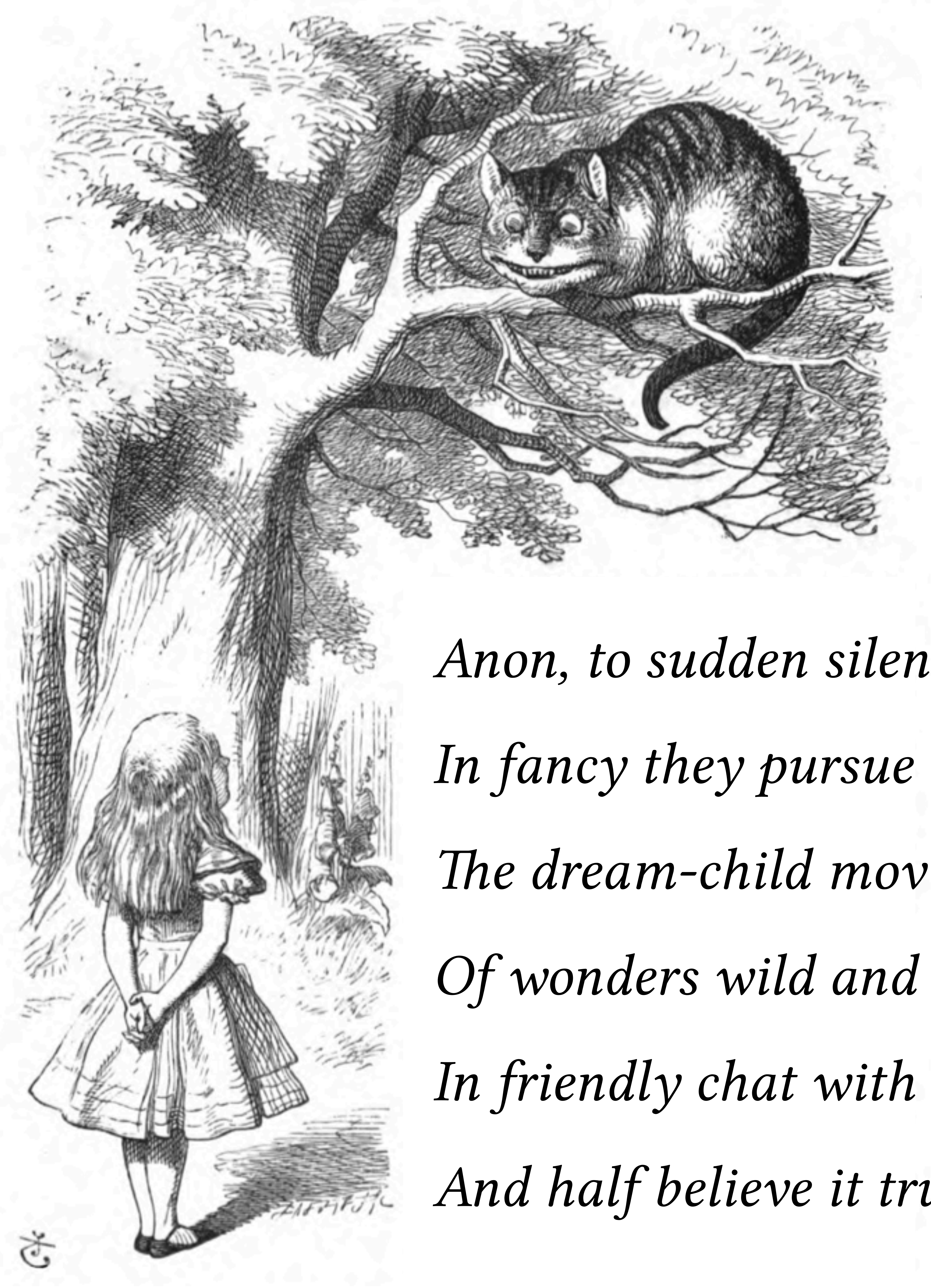
If Bob measures: $0.7^2 = 50\%$  50% 

$|\psi\rangle = \big|$  $\big\rangle$ Alice’s electron is *no longer in a superposition!*

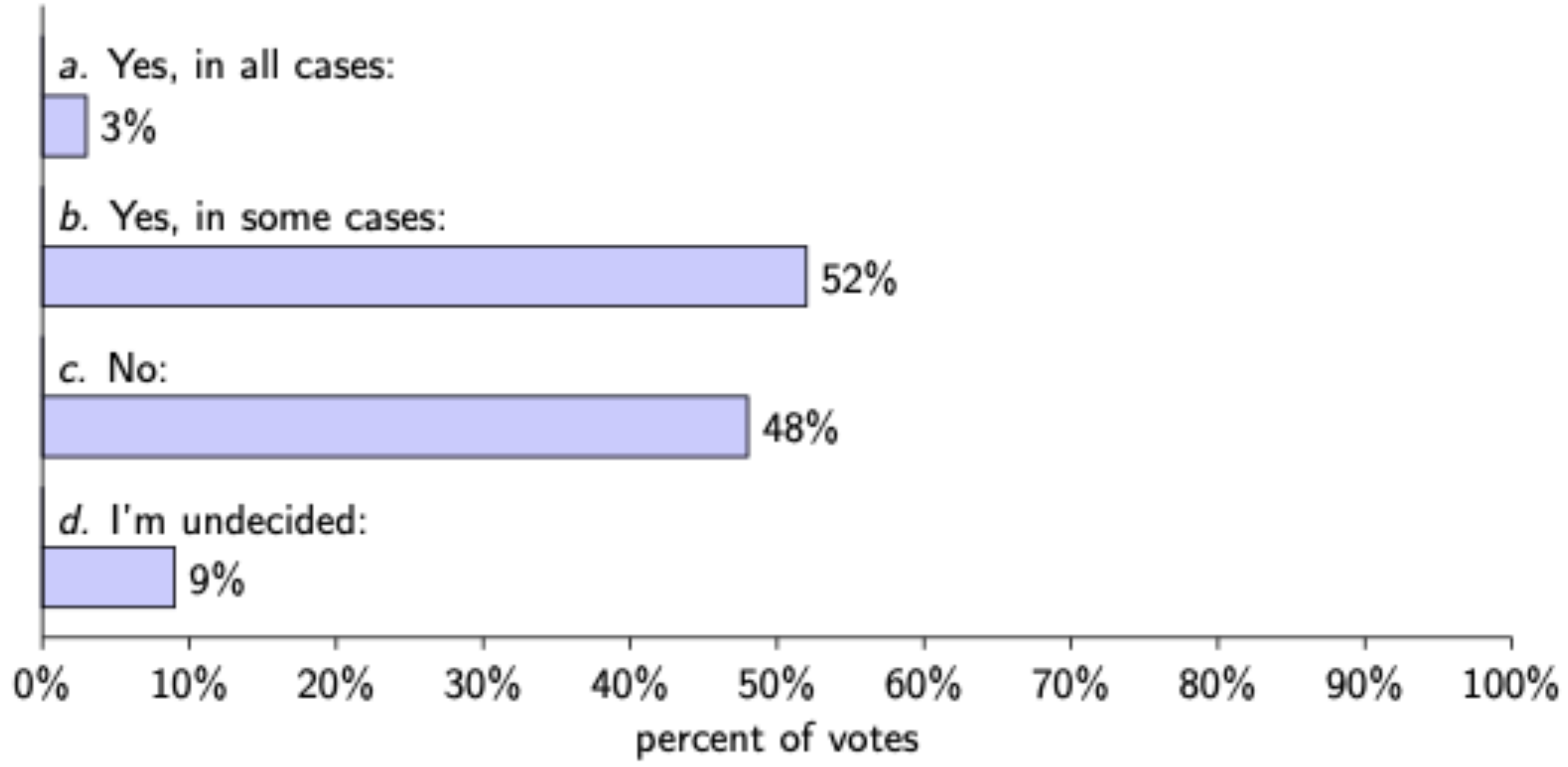
Recap: What Quantum theory says

- Classical physics couldn't explain light and atoms
- The **only theory that can** replaces classical states (list of facts)
- Quantum states $|\psi\rangle$: complex superpositions of possible outcomes
- Schrödinger equation 
- When you look: wave function collapse

- THIS SHOULD BOTHER YOU (you?? look?? collapse??)
- Most precise theory ever (magnetism of electron to 0.00000001%)



Question 2: Do you believe that physical objects have their properties well defined prior to and independent of measurement?



Anon, to sudden silence won

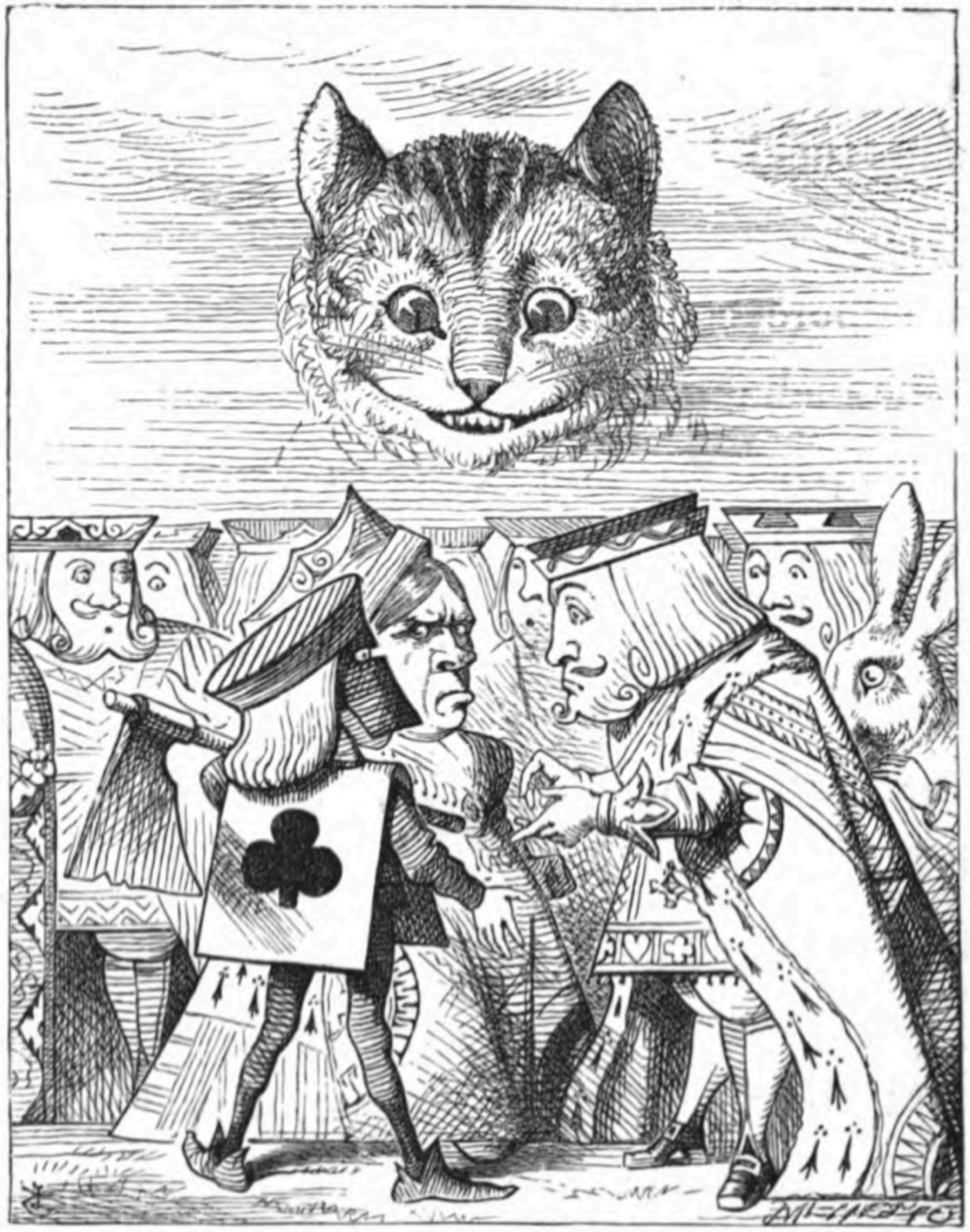
In fancy they pursue

The dream-child moving through a land

Of wonders wild and new,

In friendly chat with bird or beast—

And half believe it true.



Is this *True?*

Is this *useful?*

Does the wave function *exist?*

What is *waving?*

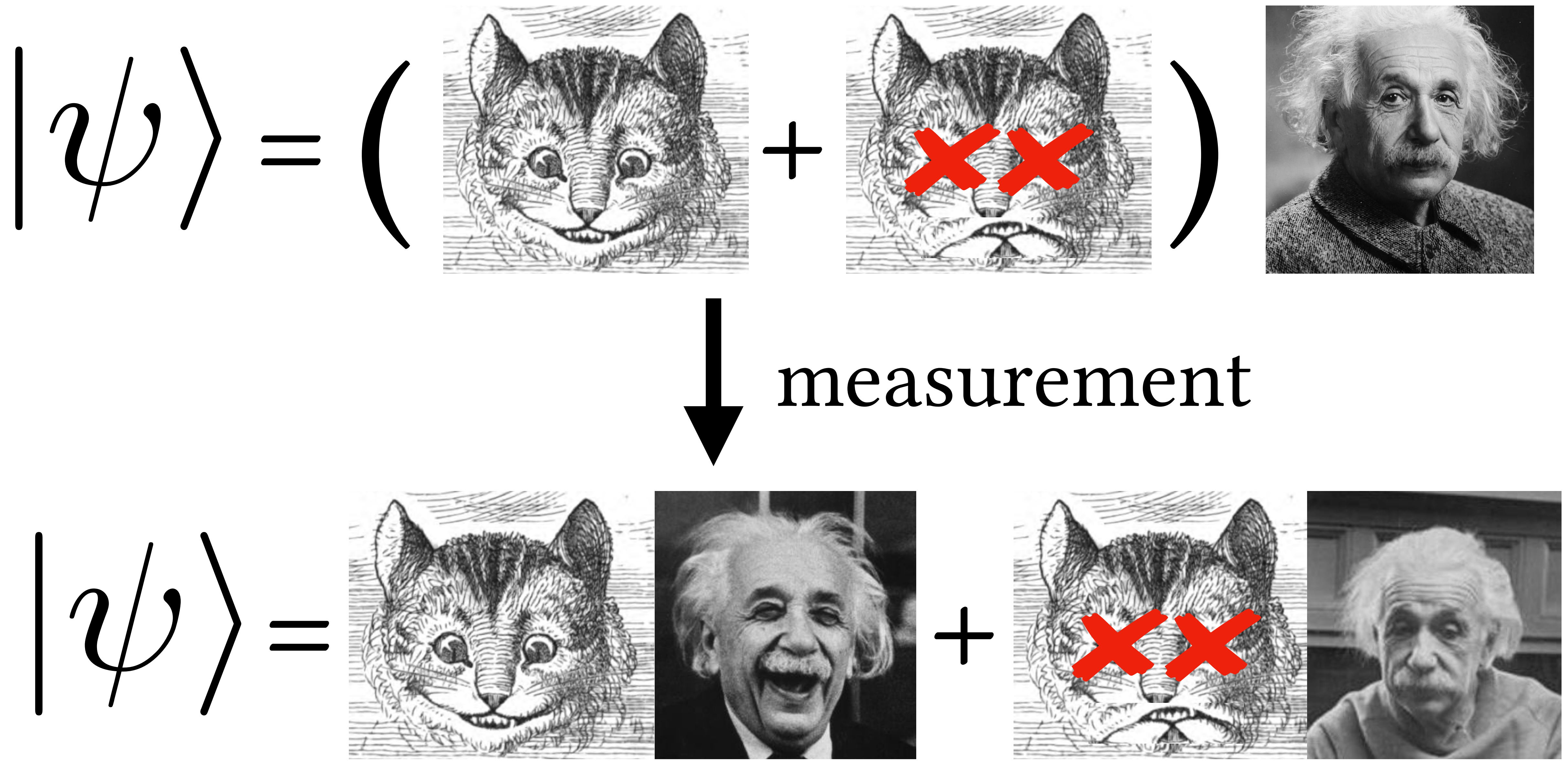
What counts as *looking?*

Copenhagen interpretation

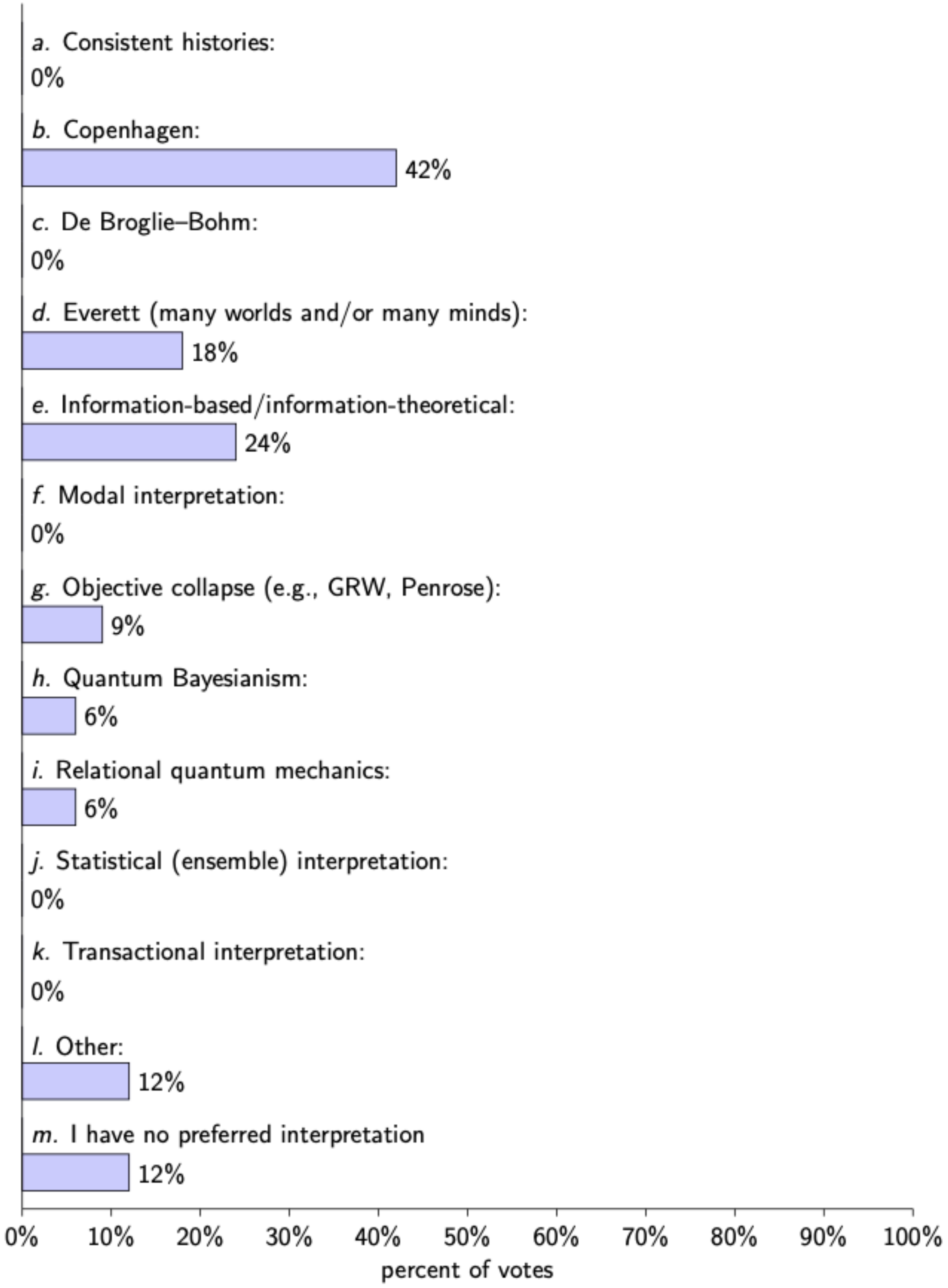
- Quantum things (small) *are in a state* $|\psi\rangle$
- Observers (big) are in a classical state
- Wave functions collapse when 'measured'
- *Shut up and calculate!*

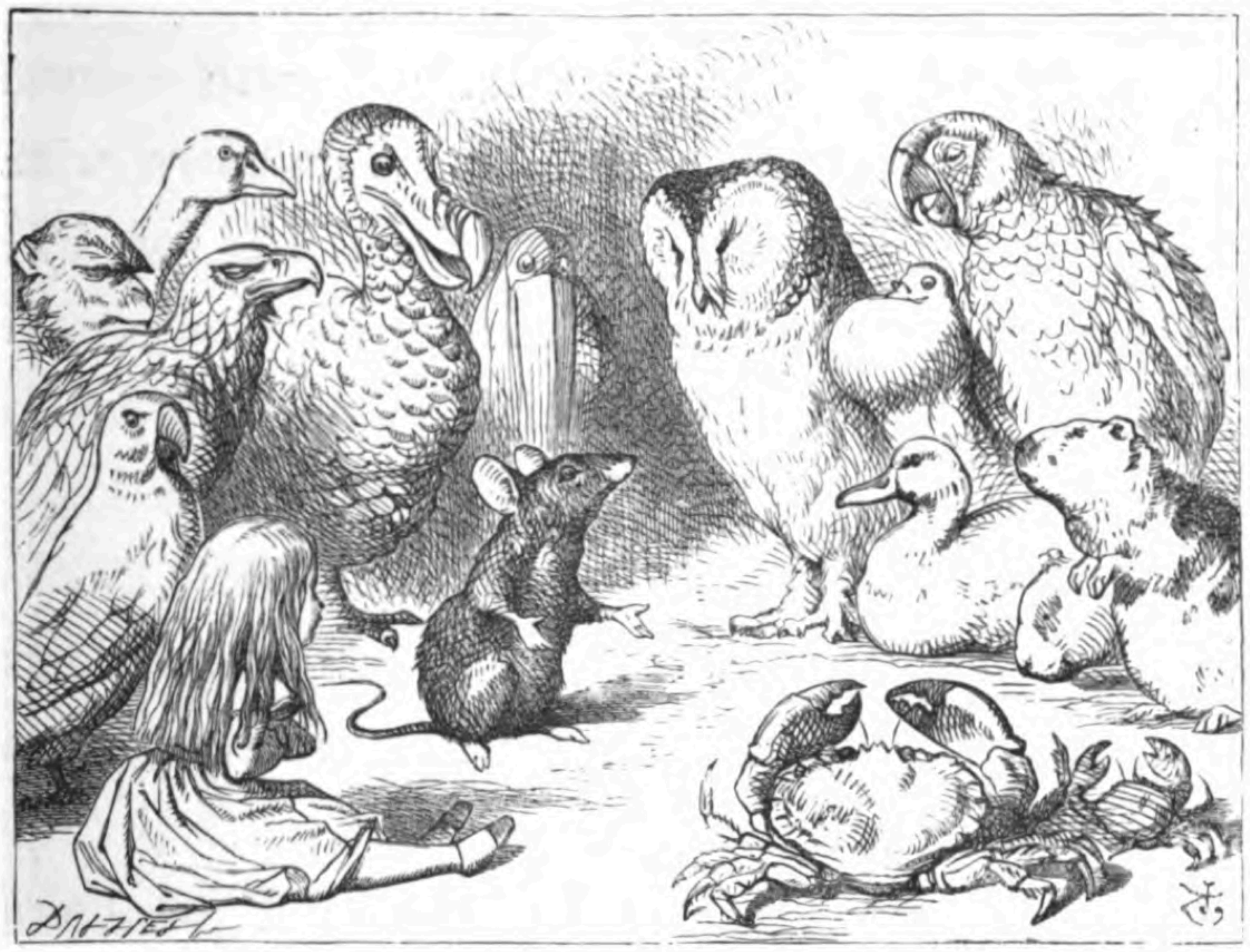
Many-worlds interpretation

- The Schrödinger equation is *everything*
- The Schrödinger equation applies to *everything*
- There is one wave function: *the universe*
- Measurement is an observer becoming entangled with the system



Question 12: What is your favorite interpretation of quantum mechanics?





Conclusion

- Quantum theory says something *very specific:*
- Things are made of wave functions that
    - Can be in a superposition
    - Can be entangled (relational)
    - Change according to the Schrödinger eq.

- It is *unclear* what this says about the fundamental nature of reality.
- The answer really matters! (I think)

Quantum computers

Complex numbers

Heisenberg uncertainty

Hidden variables

Quantum gravity

Quantum field theory