A scientific theory is based on the so-called "scientific method".

Its emergence is a result of a long philosophical debate started over 2.000 years ago and lasting until now.

Let us present a short history.

"Democritus" had the idea of atoms by "smelling" objects.
~400 ac There must be small pieces of objects floating around.

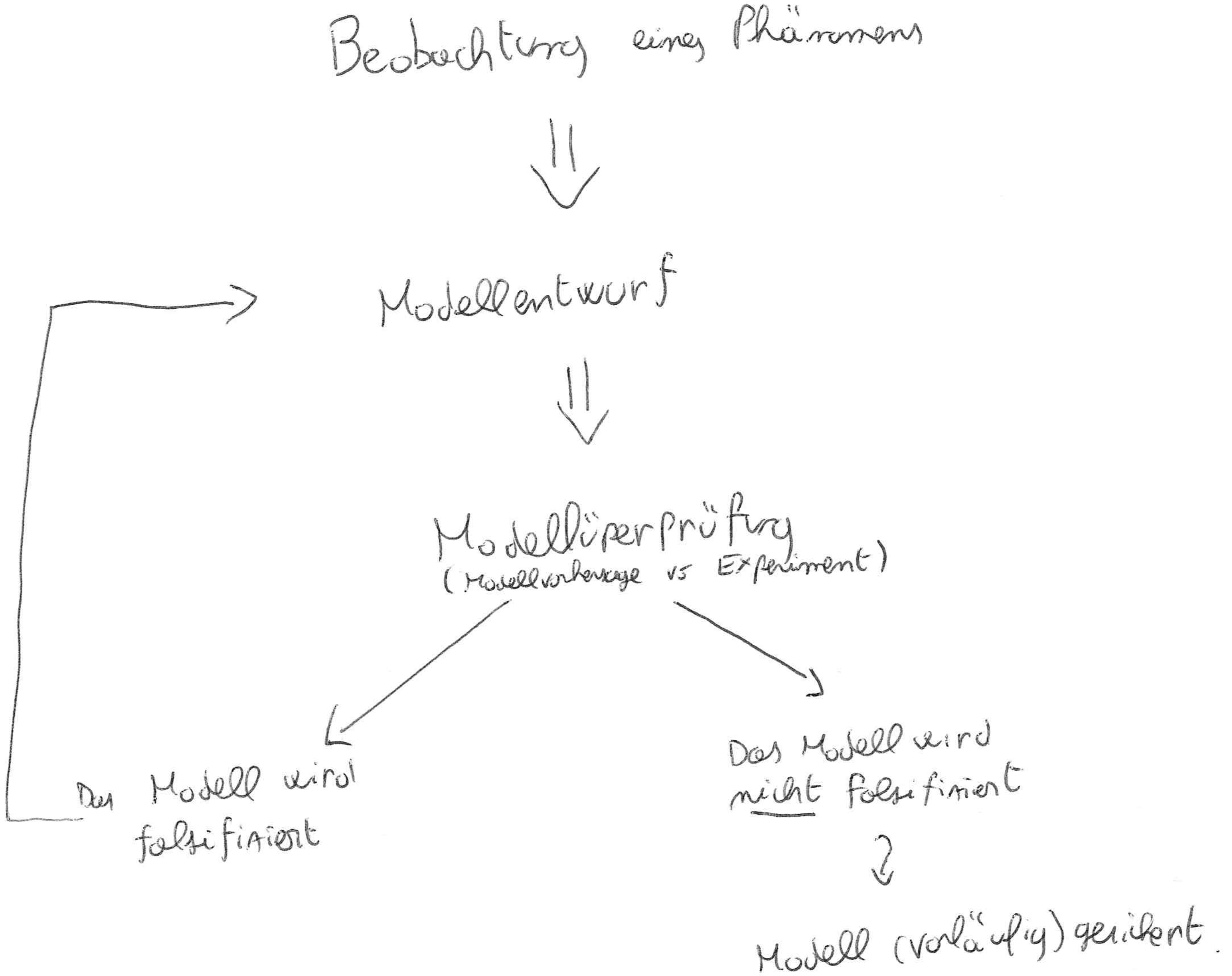
"Archimedes" : principle of Archimedes playing with soap in
~250 ac water. History of the "Golden crown" and the
dishonest goldsmith.

"Leonardo" : "Why to investigate the soul, which is not understandable
~1500 through experience? It is better to study phenomena
which are accessible to experience and can
be described by mathematics"

"Galileo" : the beginning of the scientific method.

1600

Physics and, more in general, Science (philosophia naturalis) depart from philosophy.



~> Galilei and the inclined planes

~> The PDG (Particle Data Group)

~> The search of the Higgs [illegible] at LHC follow the same scheme

Is it possible to verify a model (or a theory)?

How many verifications do we need?

It is obviously not possible to verify a theory, no matter how much evidence we gain.

⇓

Popper: a model/theory can be in a strict sense only falsified!

⇓

<u>Induction</u> can be dangerous.

Story of the turkey of Popper:
every day, at 7:00 am it is feed by the peasant. Then Christmas came...

1. EXAMPLE: ⇝ THE PARTICLE DATA GROUP $m_\gamma = 0$ ENTRY
⇝ THE PHOTON MASS IS ZERO according to theory ($\mathcal{L} = m_\gamma^2 A_\mu A^\mu$ is not allowed because of gauge invariance). How, in exp only an upper limit can be obtained.

2. EXAMPLE: g_e factor of the electron. (Gyromagnetic ratio!)

Almost perfect match of theory and experiment (QED, which is a quantum theory of fields).

$$g_e = 2\left(1+\frac{\alpha}{2\pi}+\#\alpha^2+\dots\right)$$

$$g_e : 2.0023193043617\ (15)$$

Recall:

$$\vec{m} = -g_s \mu_{Bohr} \vec{S}/\hbar$$

Going to QM

PDG → Book of "probabilities"

for instance: $f_2(1270)$ $\begin{cases} 84,8^{+2,4}_{-1,2}\,\% \mapsto \pi\pi \\ 4,6 \pm 0,4\,\% \mapsto KK \end{cases}$

. . . .

Role of the language, although not discussed previously in the scientific method, is important in each theory. Even in the context of classical mechanics we need words such as "time, space, trajectories, mass..." in order to perform a link between mathematics and physics.

In QM the role of the language is <u>even</u> more crucial due to concepts like:

observer

measurement

probabilities

As an example let us consider the Schrödinger equation:

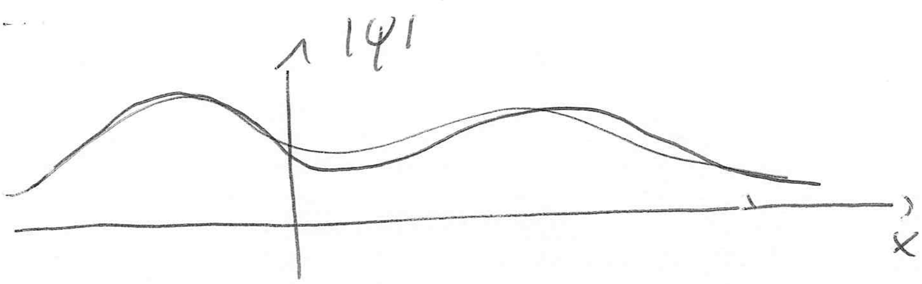
$$i\hbar\frac{\partial\Psi}{\partial t} = -\frac{\hbar^2}{2m}\Delta\Psi + V(\vec{x})\Psi$$

Originally, Schrödinger thought of a "wave of matter".

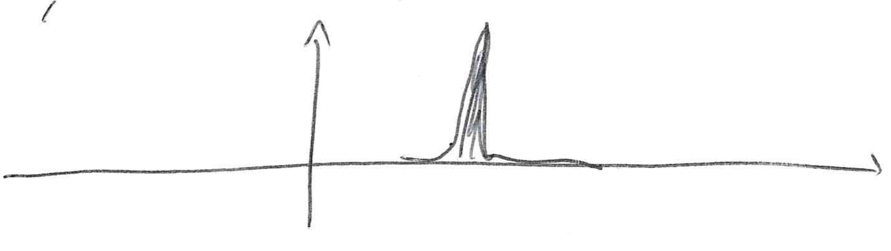
The electron is in the end a wave and not a particle.

(This is also a wave equation...)

However, this interpretation is at odd with the experiment. For instance, the intensity is proportional to $|\Psi|^2$...



By performing an experiment, we should see exactly such a pattern! But this is not true.
When performing a measurement we do not see anything like that. We always see a "small dot", i.e. something like

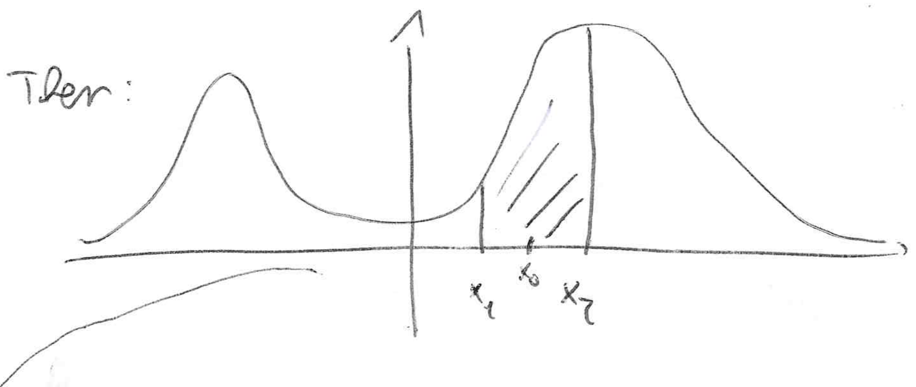


Then, in this sense the Schrödinger eq. is energy ...

but then Max Born came and said

"Let us change the interpretation: ψ does not describe a wave of matter, but a wave of <u>probability</u>"

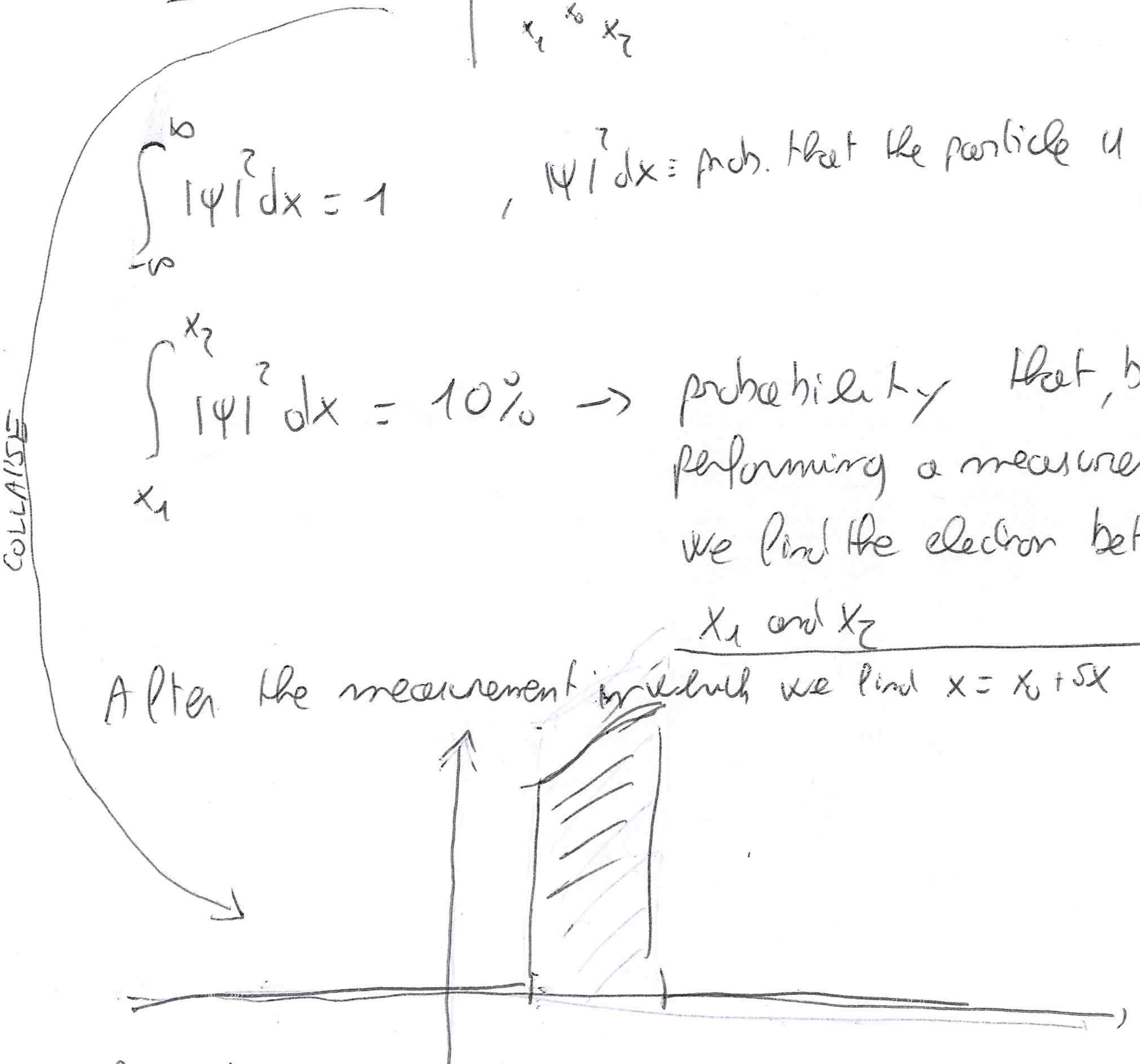
Then:



$$\int_{-\infty}^{\infty} |\psi|^2 dx = 1$$, $|\psi|^2 dx$ = prob. that the particle is between x and $x+dx$

$$\int_{x_1}^{x_2} |\psi|^2 dx = 10\%$$ → probability that, by performing a measurement we find the electron between x_1 and x_2

After the measurement in which we find $x = x_0 + \delta x$



Area = 1

By repeating the exp. we find it there again! We can verify the collapse!