Lecture 1

- XVIII – XIX century → common belief that mechanics (classical) can explain all effects
- sophisticated mathematical formalism of Lagrange and Hamilton were indeed very elegant
- however, people started to observe effects not possible to explain. Examples:

  a) <u>fotoelectric effect</u>
     → regardless of intensity, some light beams could not separate electrons from atoms

  b) electrons circulating around atoms should radiate energy, while they don't

  c) no catastrophy in UV

  d) Young experiment with 2 slits and single electron gun

So, as each theory, classical mechanics had to be improved and generalized.

↓

1st improvement → ~~specific theo~~ special theory of relativity (Einstein) $V_{max} = c$

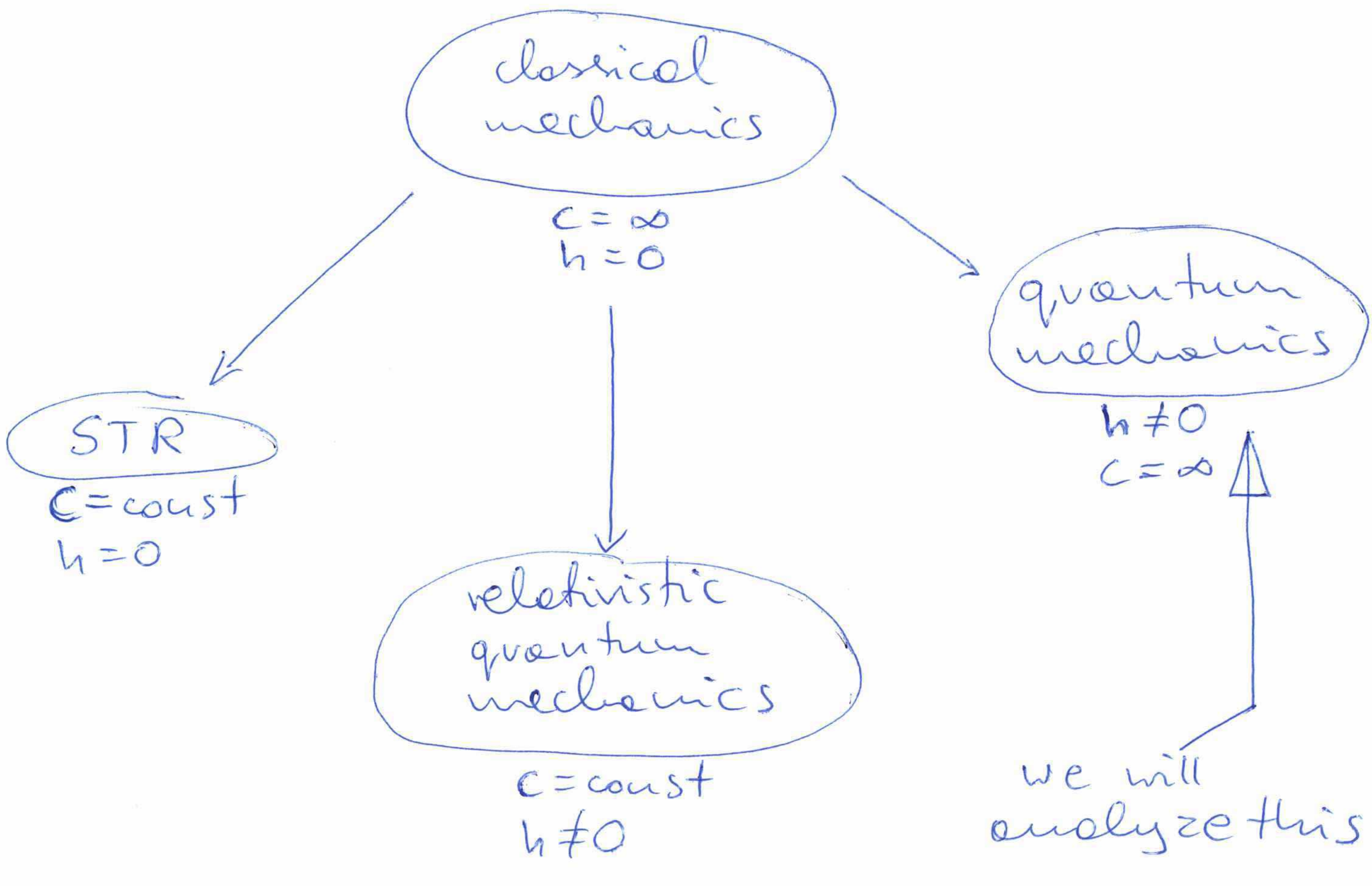
i.e.

$$V = V_1 + V_2 \longrightarrow V = \frac{V_1 + V_2}{1 + \frac{V_1 V_2}{c^2}}$$

$\Downarrow$

c - universal constant of nature

2nd improvement → quantum mechanics (rules in micro scale)



- 1900 – Max Planck postulates quantized energies of light

$$E = n \cdot \underbrace{h\nu}_{\text{quant of energy}}$$

$n \in \mathbb{N}$

h – constant, called <u>Planck constant</u>

<u>quant</u> – smallest possible quantity

$$\boxed{h = 6{,}626 \cdot 10^{-34}\ J \cdot s}$$

↓

small, but not 0!

if $h = 0 \Rightarrow$ no quantum effects → we could not exist (as atoms could not exist!)

if $h \gg 0 \Rightarrow$ quantum effects in macro scale

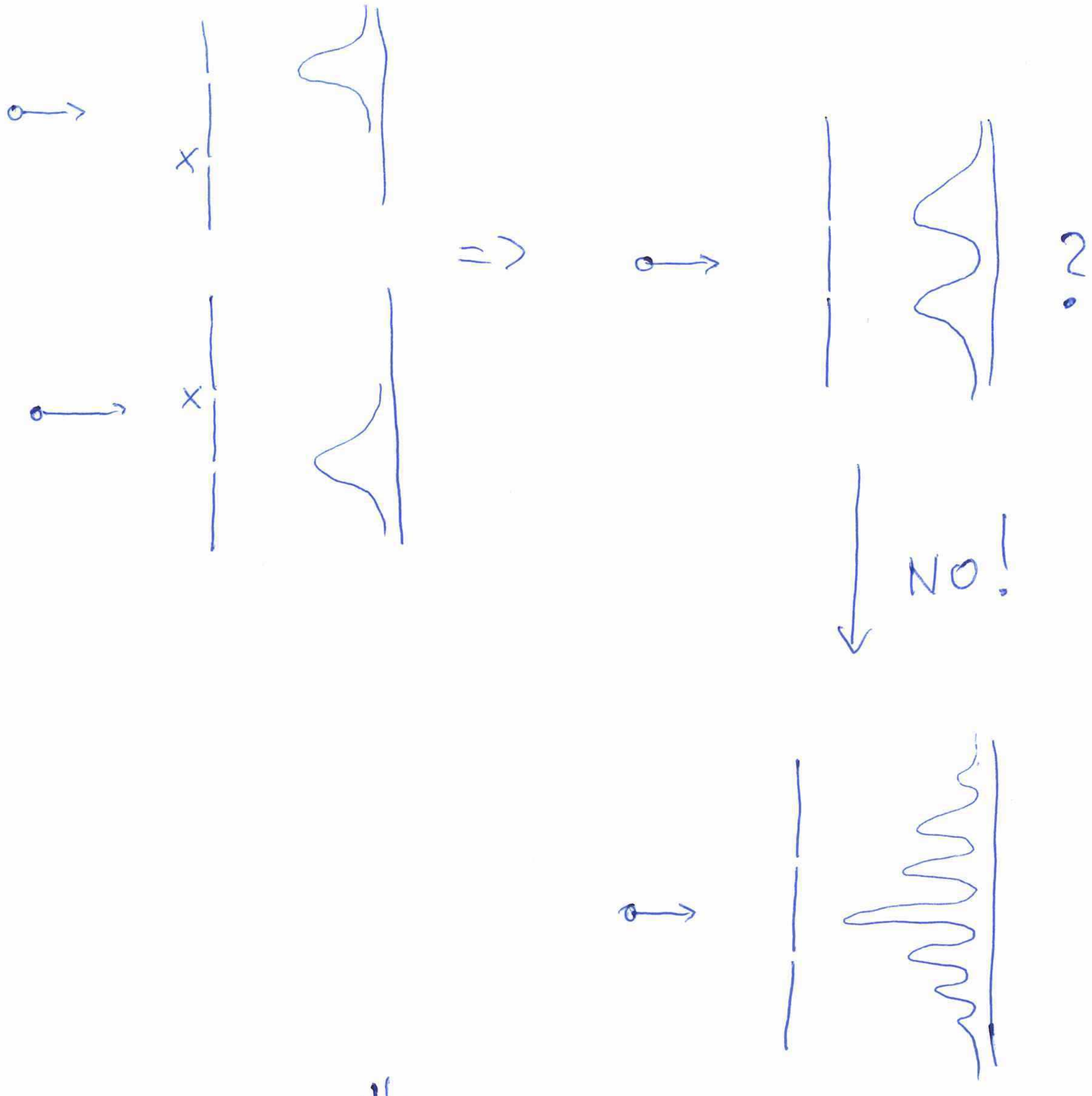
h – also constant of nature (cosmic parameter)

↓

what effects we could see if $h \gg 0$?

For example tunelling through the wall :)

Young's experiment



$\Downarrow$

electrons behave as waves!!!

$\downarrow$

$\Downarrow$

with every particle we can connect a wave (<u>de Broglie wave</u>)

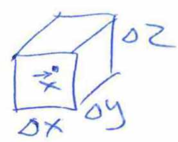
$\downarrow$

we call such wave a <u>wave function</u>

$\Psi(\vec{x})$ - wave function of particle located in $\vec{x}$

$|\Psi(\vec{x})|^2$ - probability density of finding particle in location $\vec{x}$

$|\Psi(\vec{x})|^2 \Delta x \Delta y \Delta z$ - probability of finding a particle in volume



around $\vec{x}$

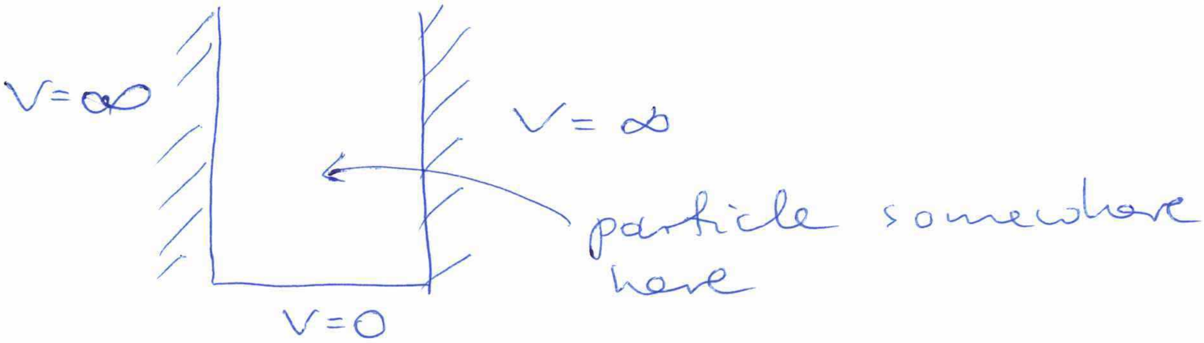
(analogy to regular density (mass density))

$\Psi = 0 \Rightarrow$ for sure there is no particle

$\Psi \neq 0 \Rightarrow$ there is not 0 probability that particle is there

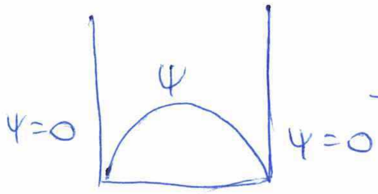
$\downarrow$

<u>Example</u>: infinite dwell of potential

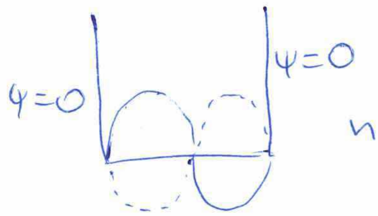


↳ quantization always results from border conditions!

V=∞ => particle can not enter
⇓
ψ=0 outside of the dwell

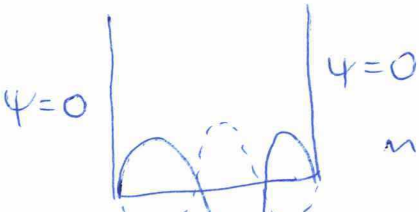


→ max length of wave => smallest energy
⇐ n=1 (ground state)



n=2

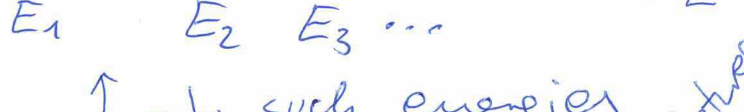
— or - - - — does not matter as probability ∝ $|\psi|^2$ not ψ



n=3

⇓

...



↑ only such energies possible – NOT in between!

→ classically particle could have any energy

There exist a fully smooth pass from quantum to classical mechanics when $h \longrightarrow 0$

In theory h could have a different value.

⇓

But would such world be possible?

<u>Quantum states</u>

$n=1 \Rightarrow \Psi_1(\vec{x}), E_1 \longrightarrow$ first possible <u>state</u>

$n=2 \Rightarrow \Psi_2(\vec{x}), E_2 \longrightarrow$ 2nd possible state

we can denote states as $\Psi_1(\vec{x}), \Psi_2(\vec{x})$

or shorter: Ψ_1, Ψ_2

or even shorter: $|1\rangle, |2\rangle$

here we put parameters which uniquely identify the state (so called quantum numbers)

↓

For our example we have infinite number of states, but these are <u>discrete</u> not continuous

$$|1\rangle, |2\rangle, |3\rangle, \ldots$$

But according to quantum mechanics, particle can also be in a state, which is a linear combination of such basis states:

$$|\psi\rangle = \alpha_1 |1\rangle + \alpha_2 |2\rangle + \alpha_3 |3\rangle + \ldots$$

$\alpha_1, \alpha_2, \alpha_3 \ldots$ – numbers (complex :)) called amplitudes

with condition (called normalization) that

$$|\alpha_1|^2 + |\alpha_2|^2 + |\alpha_3|^2 + \ldots = 1$$

For example

$$|\psi_a\rangle = \frac{1}{\sqrt{2}} |1\rangle + \frac{1}{\sqrt{2}} |3\rangle$$

or

$$|\psi_b\rangle = \frac{1}{\sqrt{3}} |1\rangle + \frac{1}{\sqrt{3}} |2\rangle + \frac{1}{\sqrt{3}} |3\rangle$$

etc. ↓

So, how all this relates to quantum computers?

Classical bits: 0 or 1

- either 0 or 1, nothing else possible

In quantum computers we generalise these 0 and 1 to be quantum states and then bit $\longrightarrow$ quantum bit or in short QUBIT

BIT		QUBIT
0 or 1	$\longrightarrow$	$\|0\rangle$ or $\|1\rangle$
		or $\alpha\|0\rangle + \beta\|1\rangle$!!!

So quantum bits can be $|0\rangle$, $|1\rangle$ or a supperposition of $|0\rangle$ and $|1\rangle$ <u>at the same time</u>

to be continued... :)