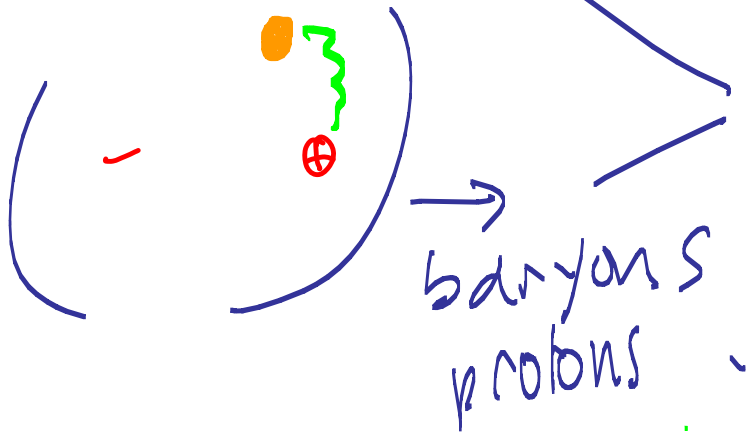


Emergence lec. 9 2011

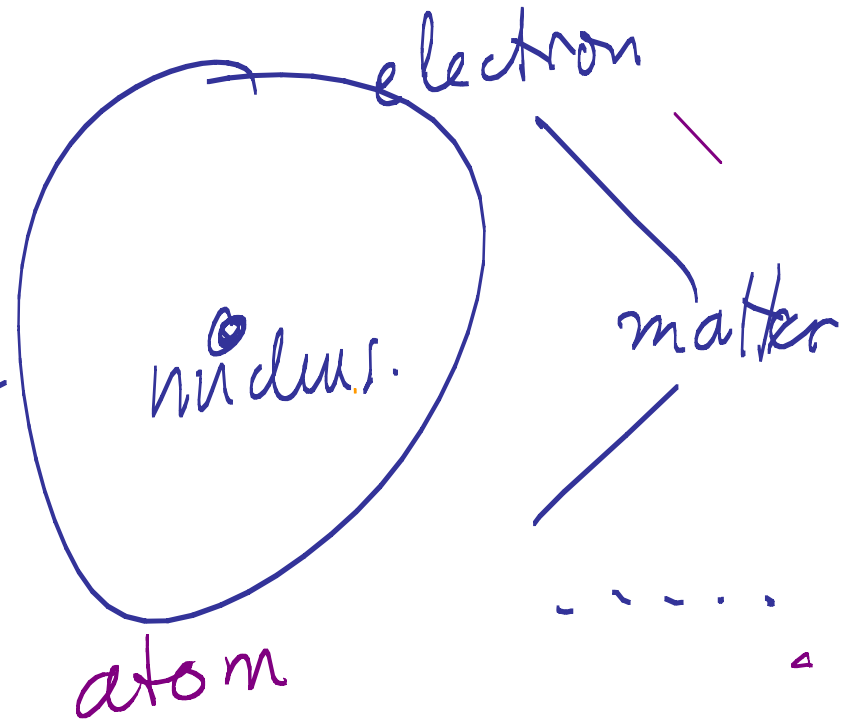
bottom up
standard model

quarks
lepton
4 forces.



nucleon

hierarchical picture



why this hierarchy?

why these rules, masses etc.

$m_{\text{proton}} \sim 1820 \times \text{mass of electron}$

→ all of these "facts" are emergent.

Standard Model (quantum mech + special relativity)

↔ general relativity → BIG BANG

"facts" "explained" by early
universe evolution,
crucial general ideas

Determinism \leftrightarrow randomness.
"indeterminism"

Symmetry \leftrightarrow asymmetry
"broken symmetry"

Newton's laws are
deterministic,
— perfect clockwork

Newton

Laws
perfect
"initial
"data"



exact
outcomes

NO RANDOM
ness
at all

quantum
mech.

ψ

"wave
function"

object of theory

← encodes
"probability
amplitudes"

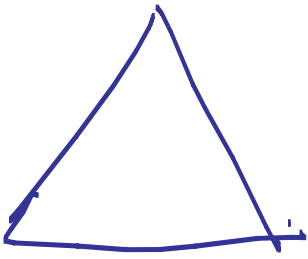
$|\psi|^2 \sim$ probability of observation.

— fluctuations } fundamental
— randomness }

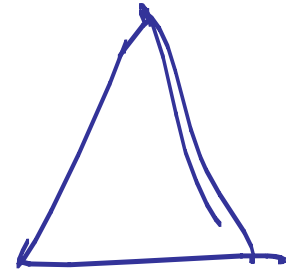
symmetry \leftrightarrow "broken" symmetry

= an "operation" that
leaves something unchanged.
"invariant",

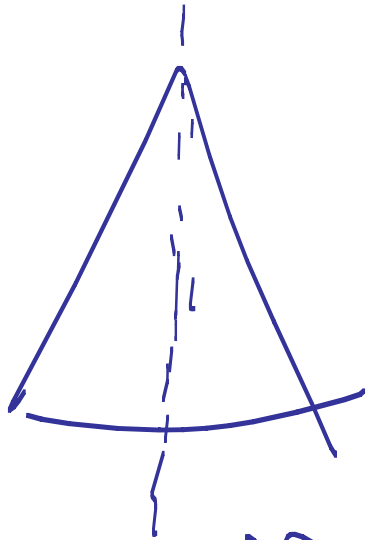
equilateral
triangle



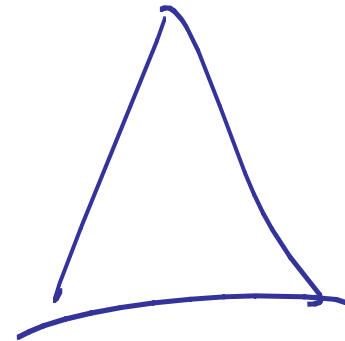
rotate
↶
 120°



reflect
→
across
plane



mirror
plane

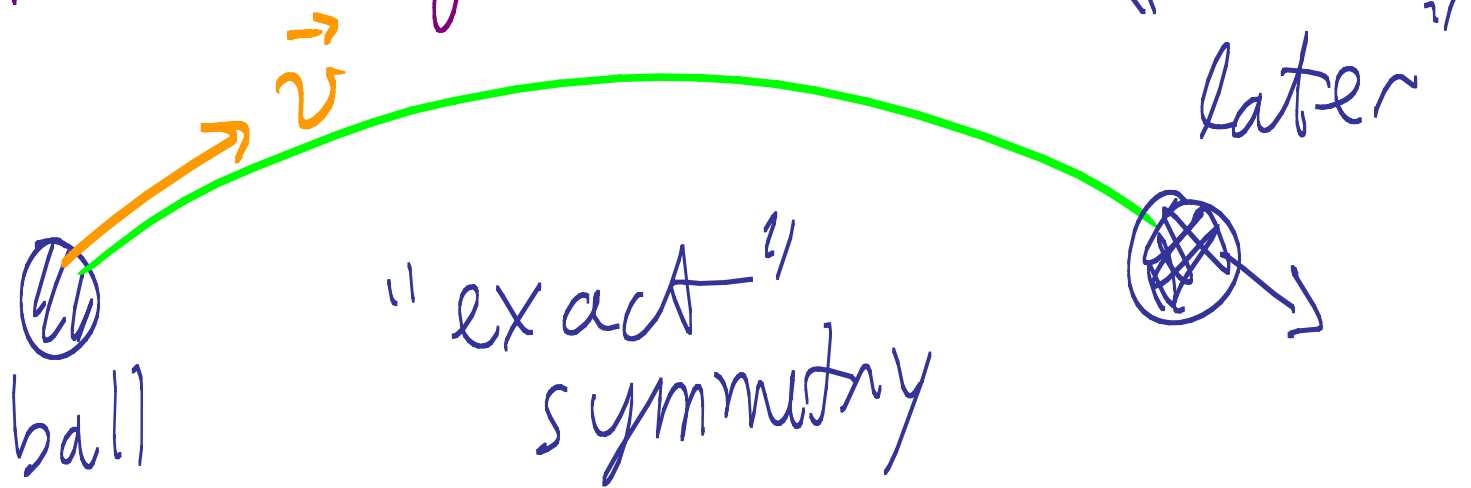


reflection
symmetry

Newton's Dynamics are
time reversal symmetry

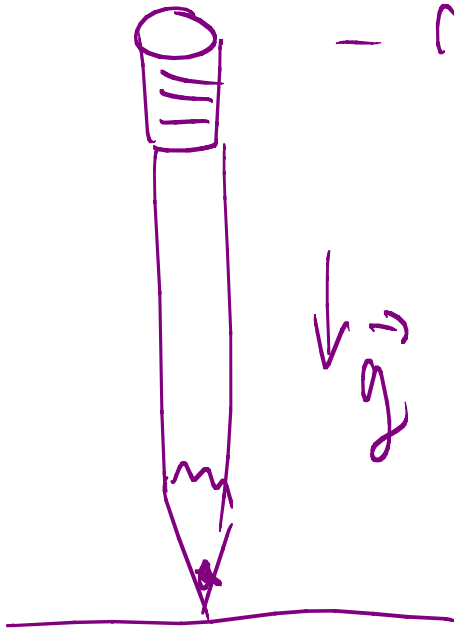
$$t \leftrightarrow -t$$

past \leftrightarrow future



BROKEN symmetry.

- rotational symmetry.



↓
"g"

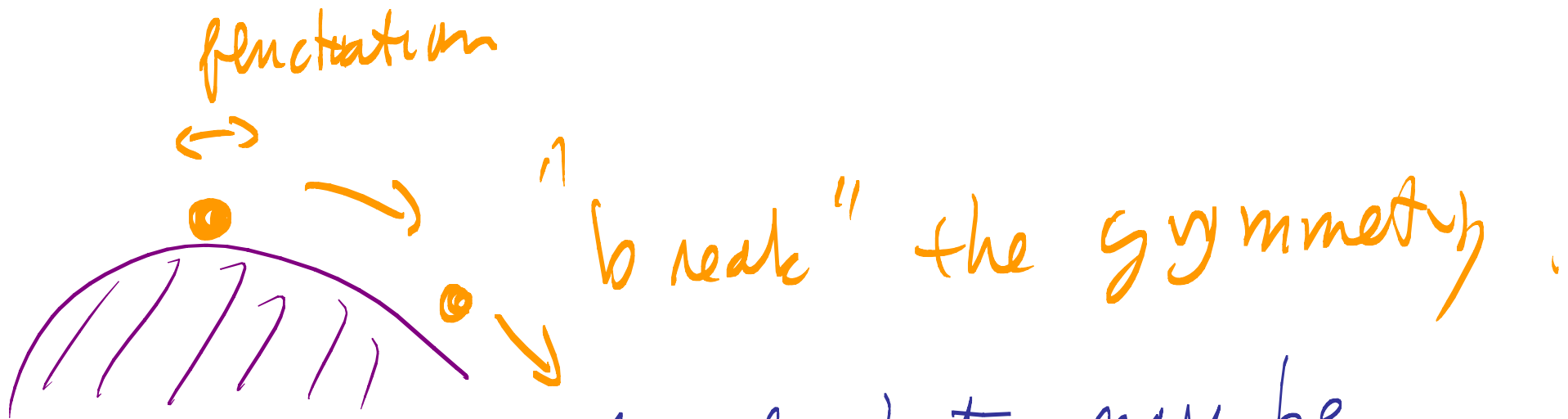
→
"spontaneously"



fluctuations (quantum)

→ instability

→ non symmetric states.



symmetry of final state may be
"less" or "lower" symmetry
than initial conditions
→ amplification of initial fluctuations

ingredient of EMERGENCE:

→ symmetry breaking by
amplification of fluctuations
in unstable situations.

CONTINGENCY.

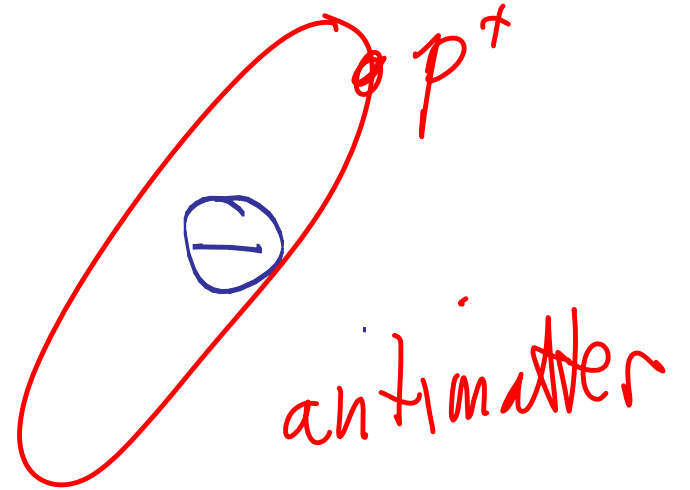
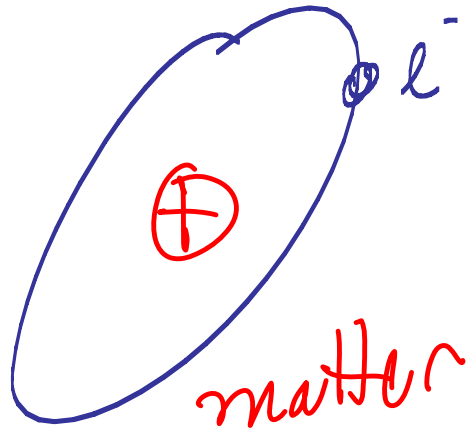
Matter \leftrightarrow antimatter symmetry

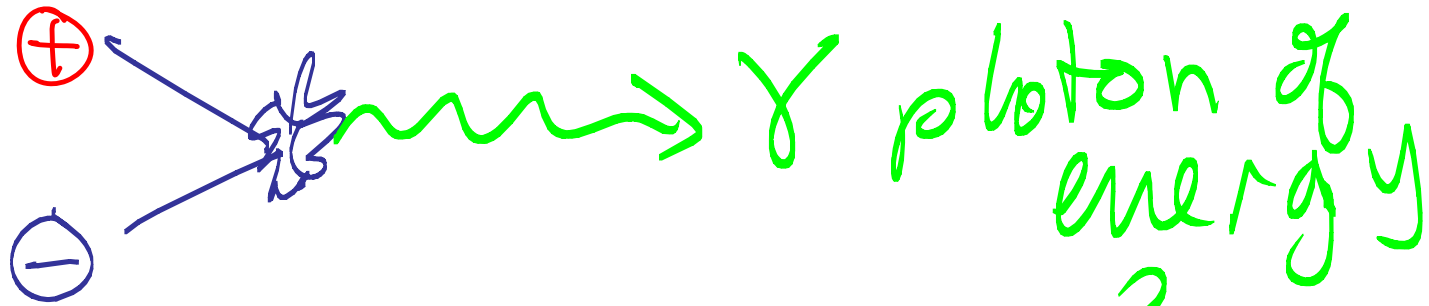
\ominus electron

\oplus "positron"

positron is exactly "mirror image"
of electron

antimatter \longleftrightarrow matter





"annihilation" $2mc^2$