Symmetry and Parallel Universes

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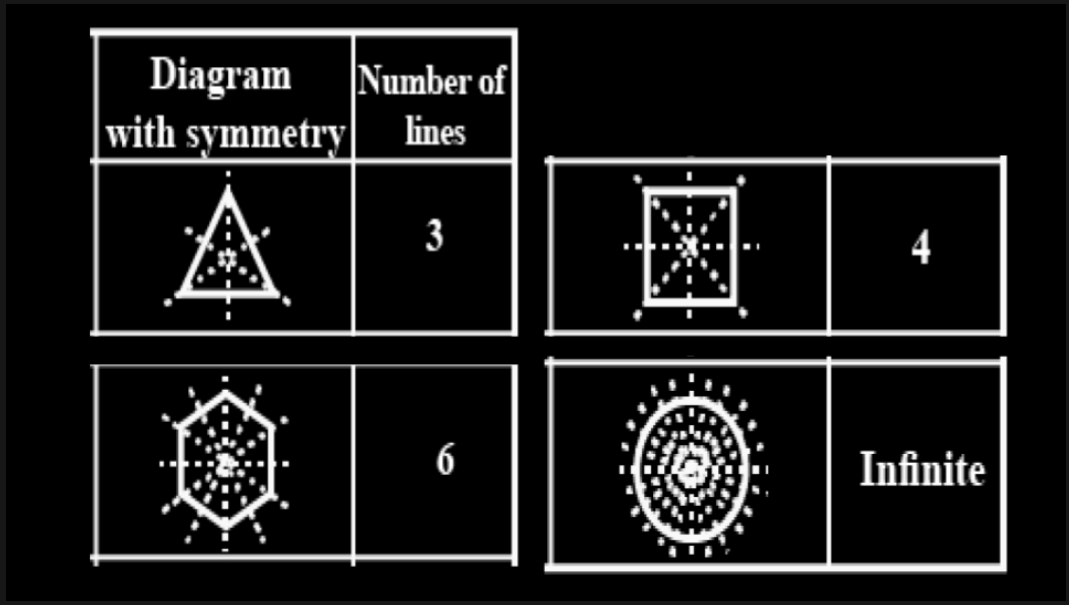
Physics: the study of the Universe and its behavior through space and time

Objective: Understand better how symmetry helps us study the Universe around us

What is Symmetry?



Symmetry tells us how symmetric things are!

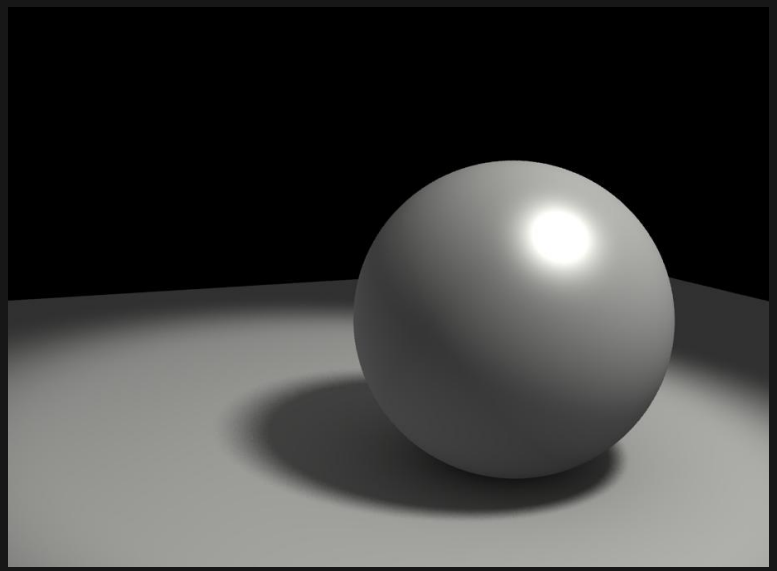
Definition (Symmetry)

Symmetry is the principle that describes how many operations we can do without changing what something looks like.

Symmetry in Physics

Example (Uniform Compression)

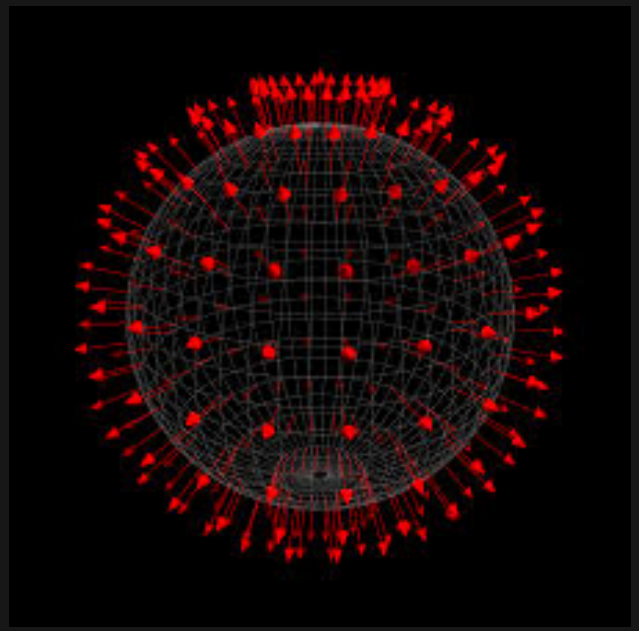
Consider a perfect 3D sphere (ball). Compress it uniformly on all sides. What is its final shape?



Symmetry in Physics

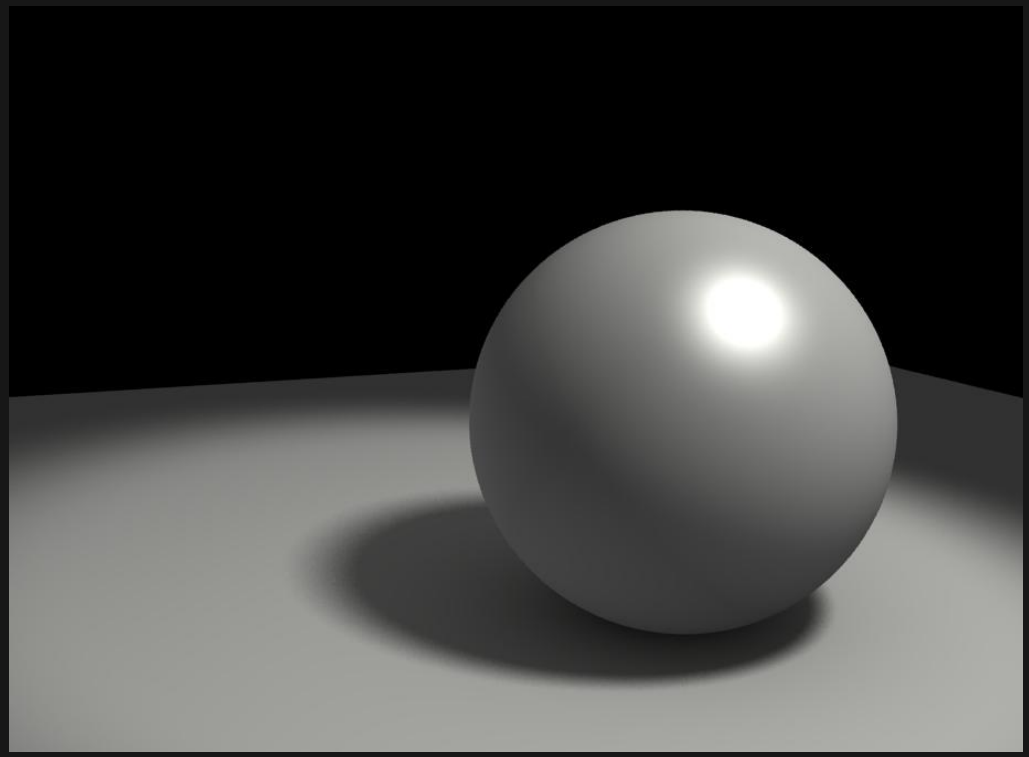
Example (Uniform Compression)

Consider a perfect 3D sphere (ball). Compress it uniformly on all sides. What is its final shape?
A sphere! Spherical symmetry is conserved.



Symmetry in Physics: Perfect Objects

Perfect Objects



Only truly exists in our imagination. But a good approximation!

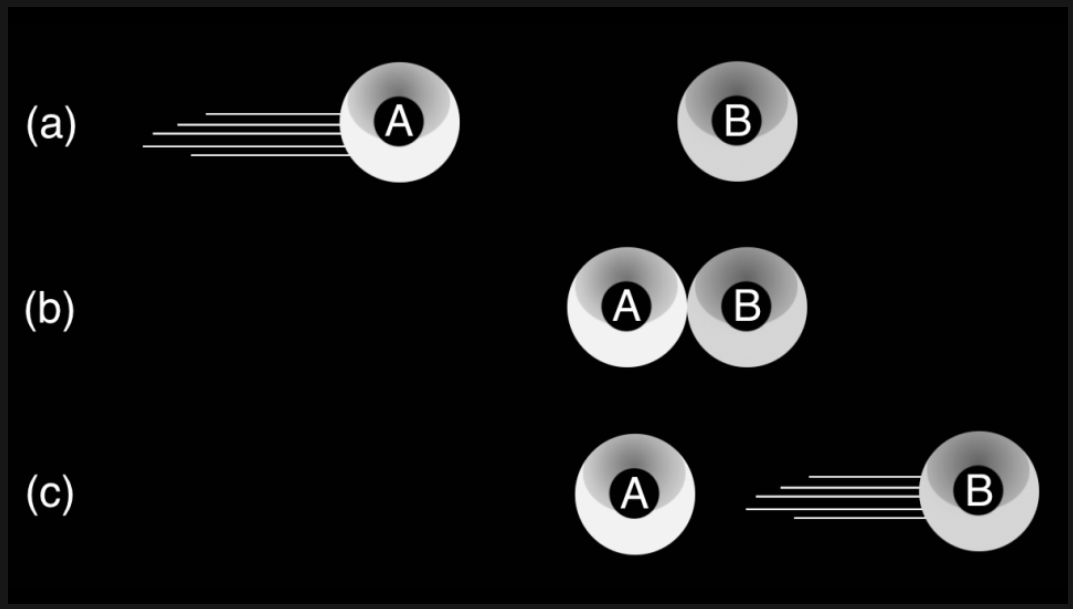
Symmetry in Physics: Uniform Randomness

Isotropic symmetry. Ex: Universe, paramagnets,

While not perfect any deviations that exist are random and on average are 0.

Symmetry in Physics: Fundamental

Time Reversal symmetry. Ex: Newton's Laws, Momentum



Time can be reversed

Symmetry as a Tool in Physics

Theorem (Symmetry Conservation Principle)

If things start with symmetry, they respect that symmetry.

Any Questions?

- Symmetry exists
- Symmetry is important
- Symmetry is conserved

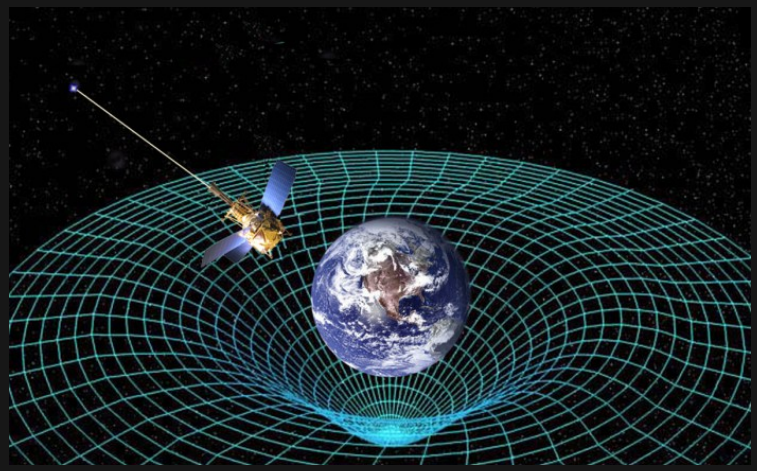
Broken Symmetry

Corollary (Symmetry Principle)

If things break symmetry, there must be a source of that symmetry breaking.

Solve for the source of asymmetry!

For each point particle, mass m_1, m_2, Newton's Law of Gravitation Spherical symmetry. But, forces are between point particles.



Source is: the setup of the problem!

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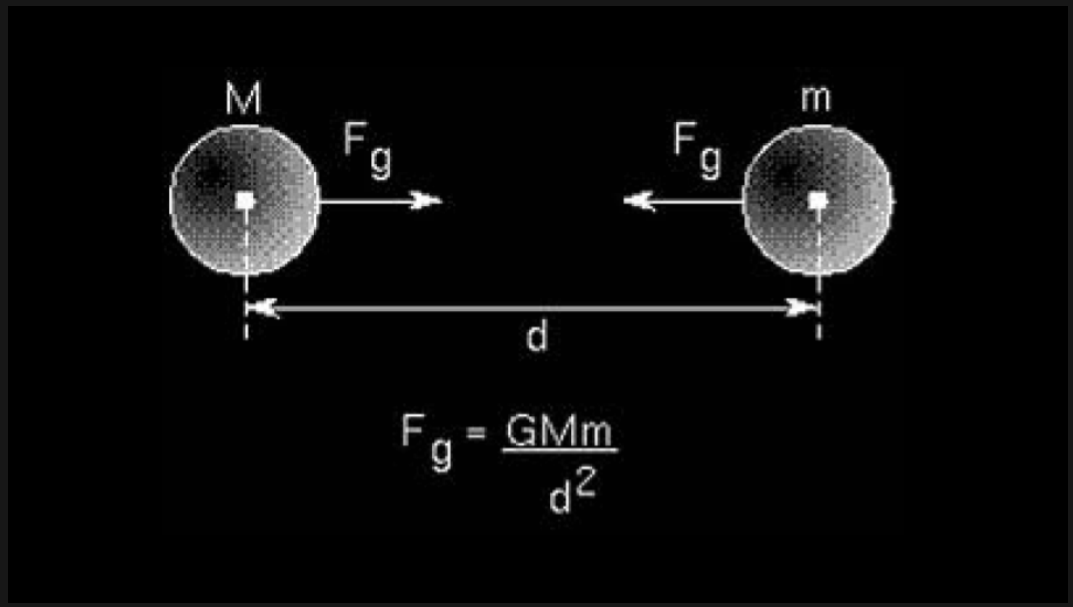
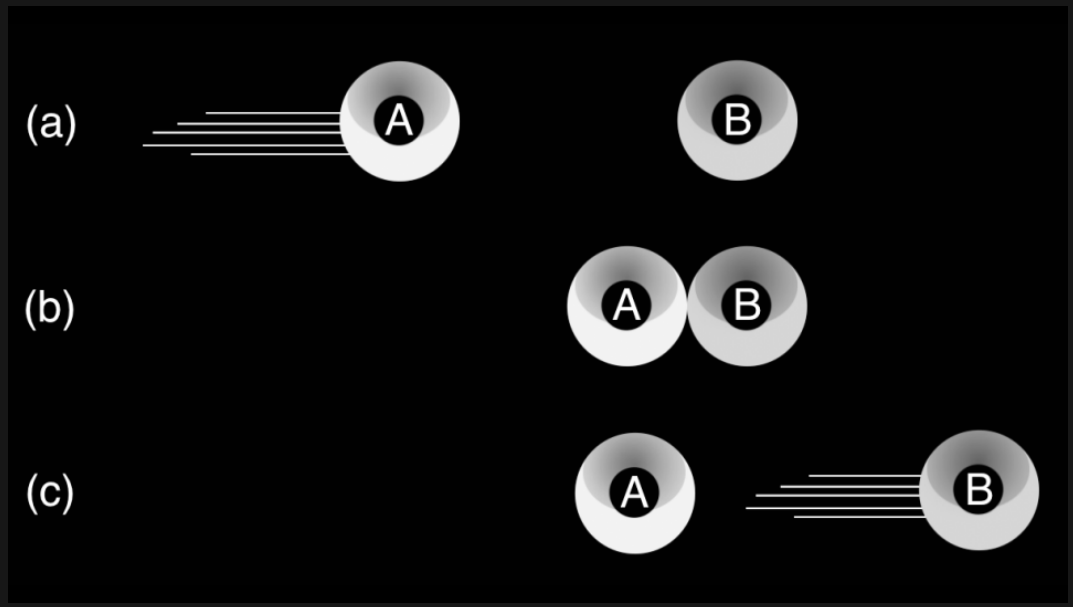


Source is: the setup of the problem!

Breaking Time Reversal Symmetry

For Newton's Laws, Time Reversal Symmetry. Consider boiling water.



How do you unboil water? (Entropy always increases)

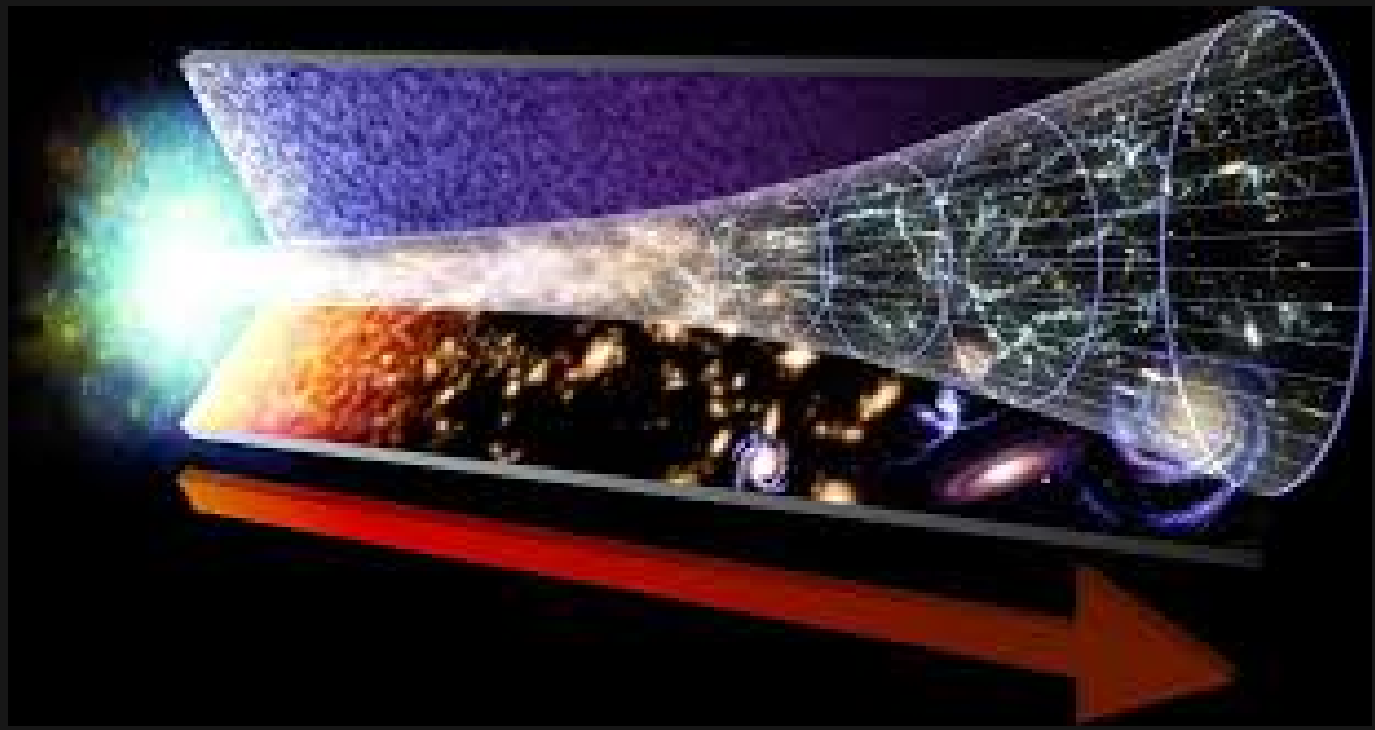
Breaking Time Reversal Symmetry

For Newton's Laws, Time Reversal Symmetry. Consider boiling water.

How do you unboil water? (Entropy always increases)

Break TRS via Causality

The source is: **Causality**!



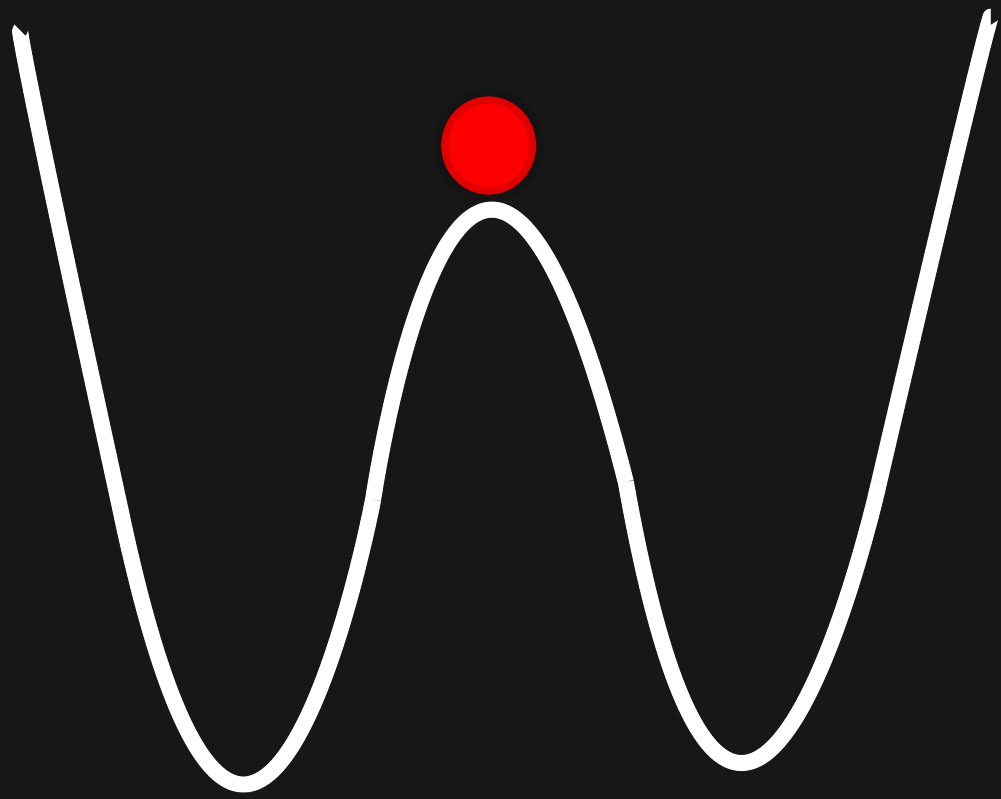
Fancy quote to take away:

> *Causality is the source of Time Reversal Symmetry breaking of Newtonian mechanics and leads to an arrow of time inherent in the second law of thermodynamics*

Newton didn't embed causality into his theory. What a dumb dumb

Solve for the source of asymmetry!

Ball on hill, Mirror symmetry. Let it drop.



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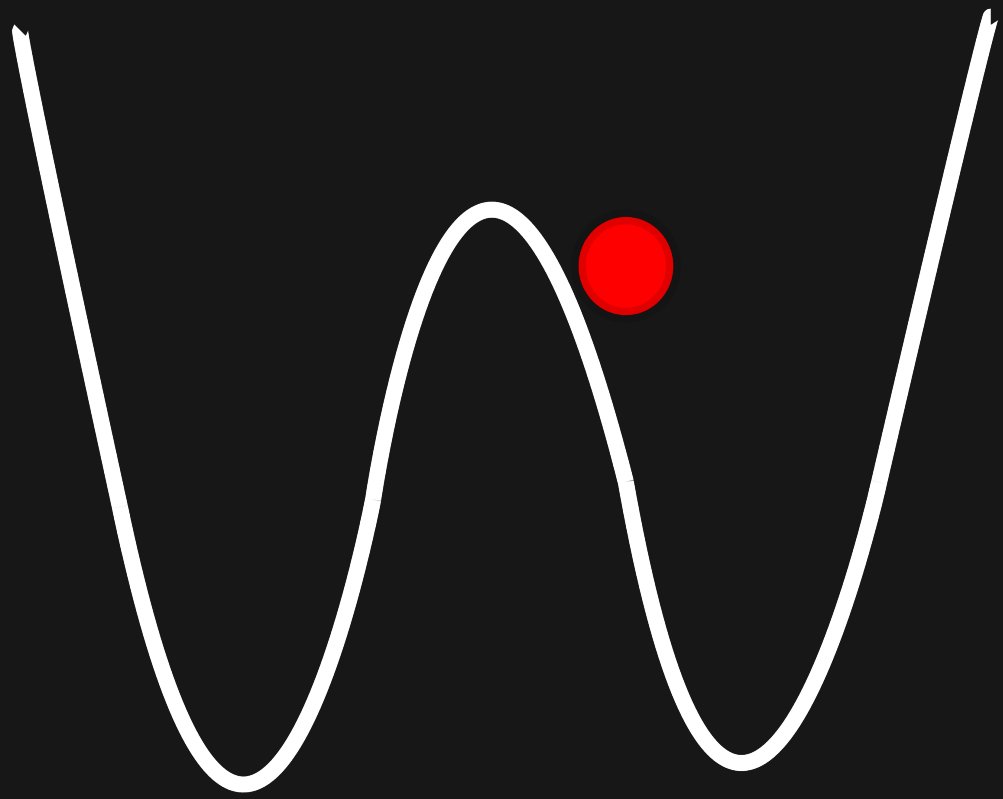

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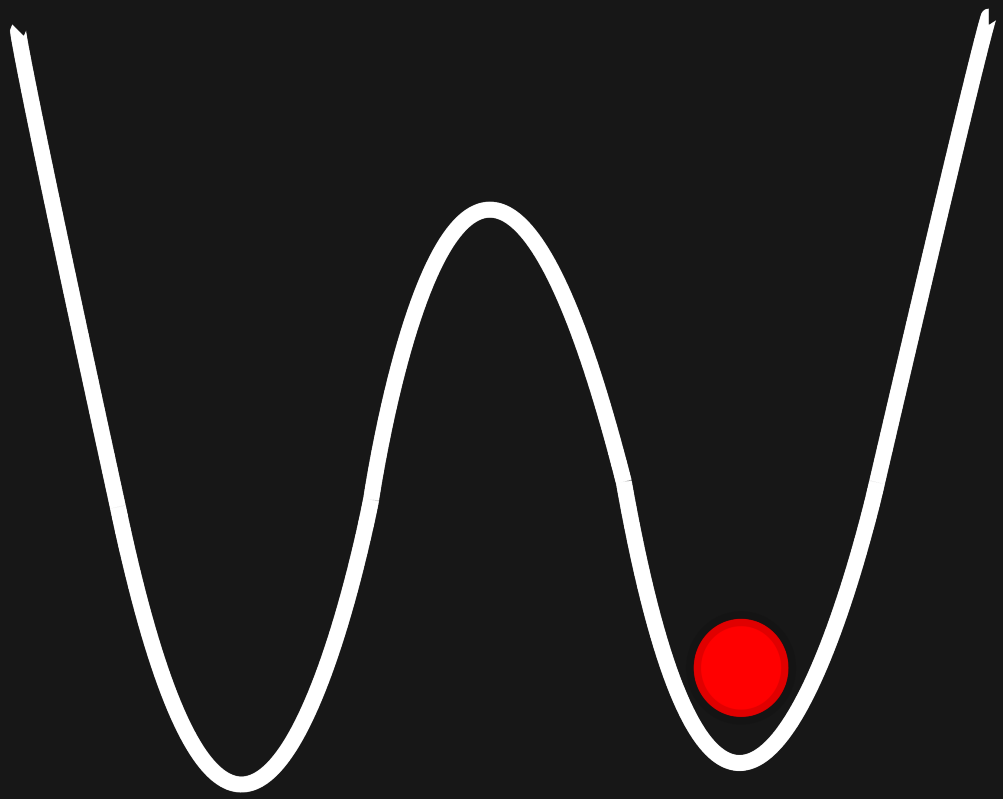


The source is: :(

Symmetry not Conserved?

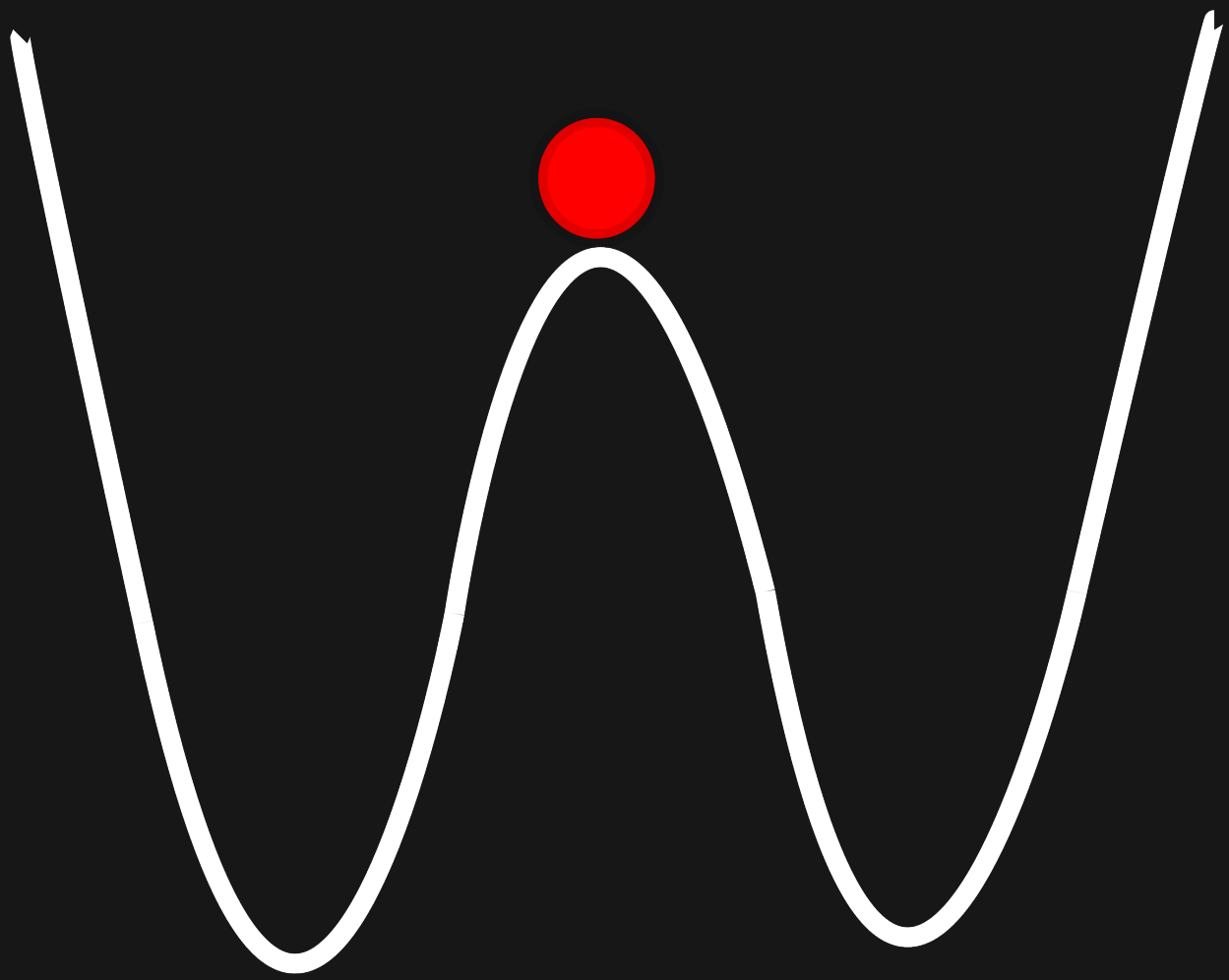
Symmetry is not conserved and we can't find out why

Definition (Spontaneous Symmetry Breaking)

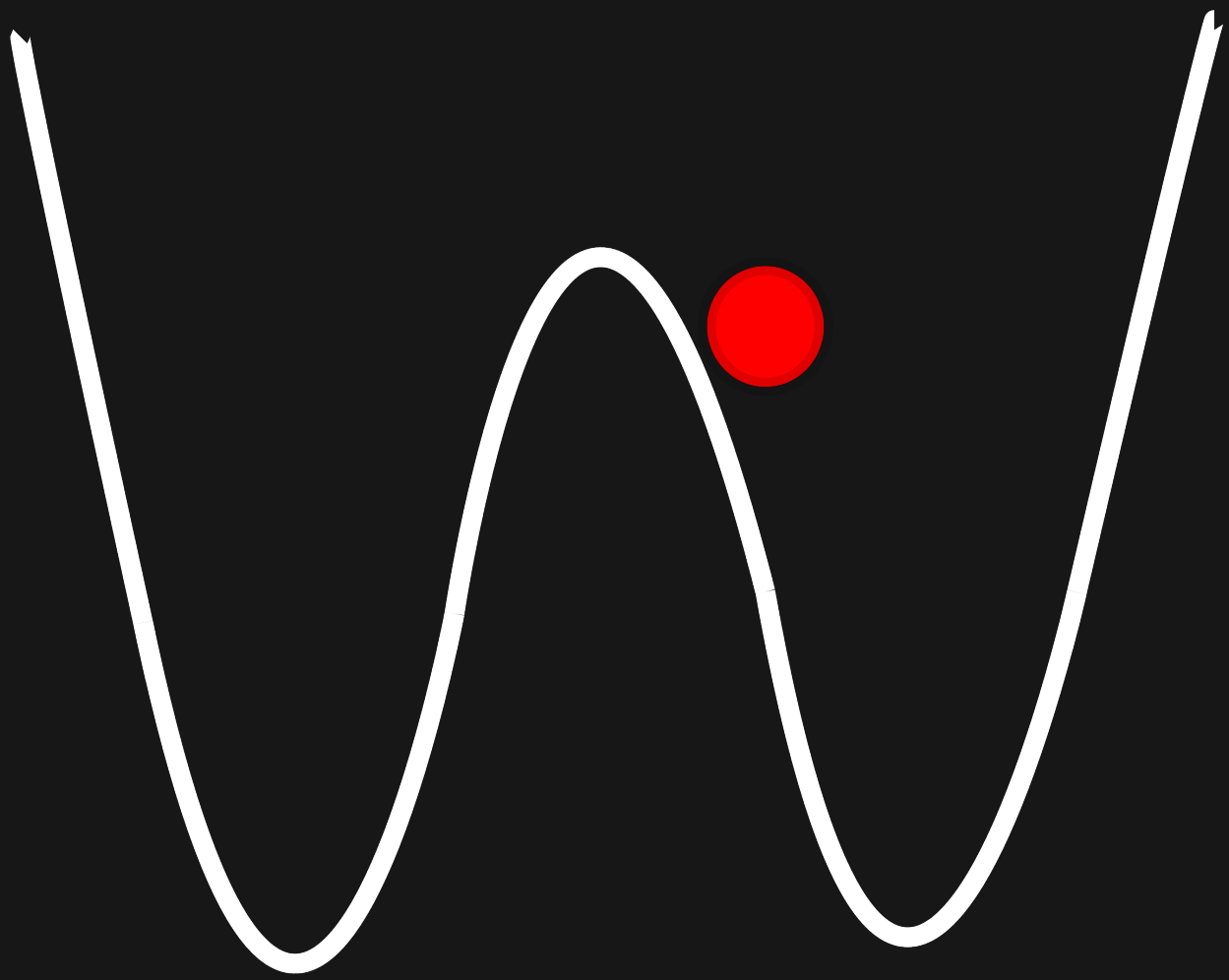
The phenomenon when a system **seems** to break its own symmetry

Let's watch a SIMULATION.

Hill (Symmetry conserved)



Hill (Symmetry breaking!)



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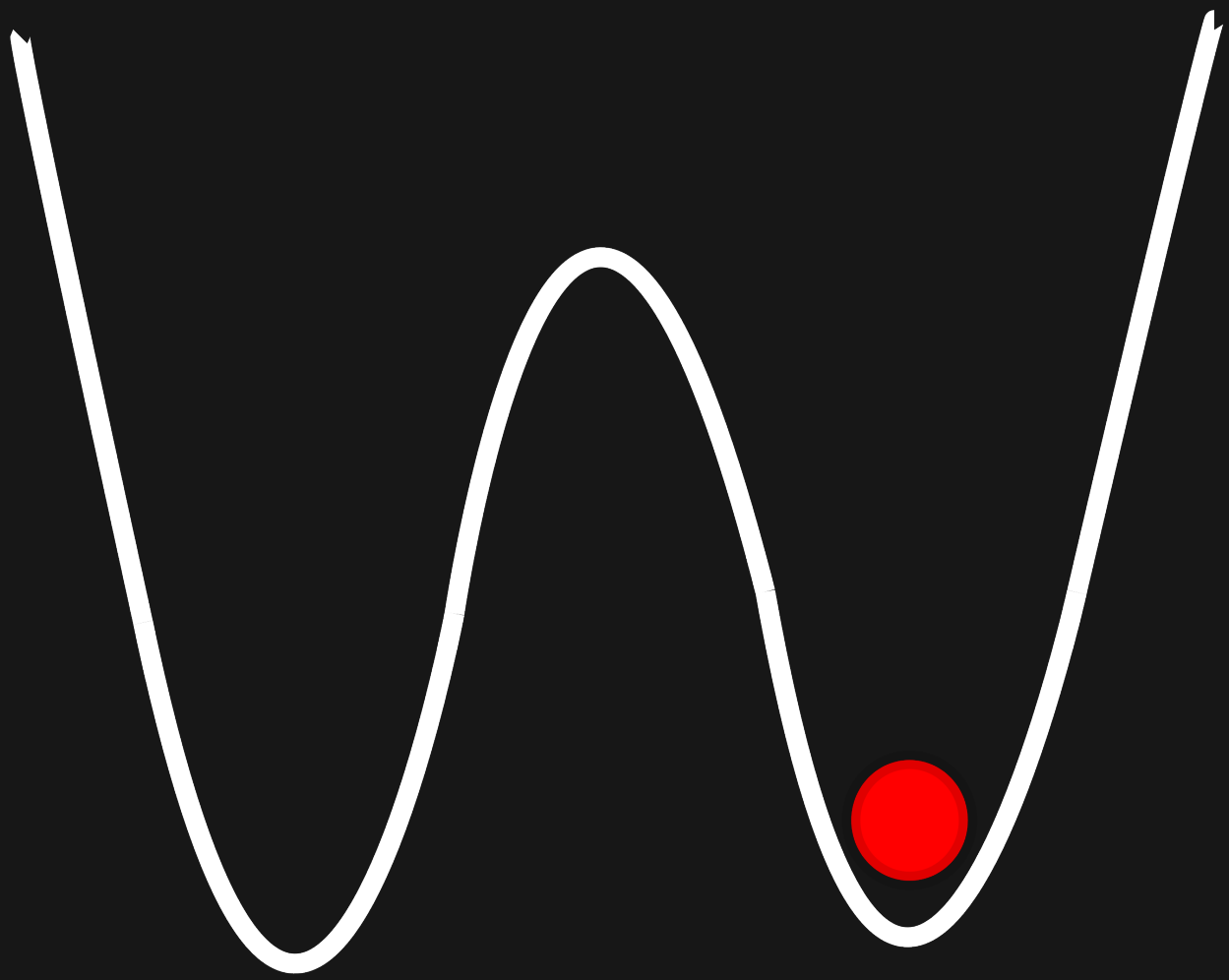

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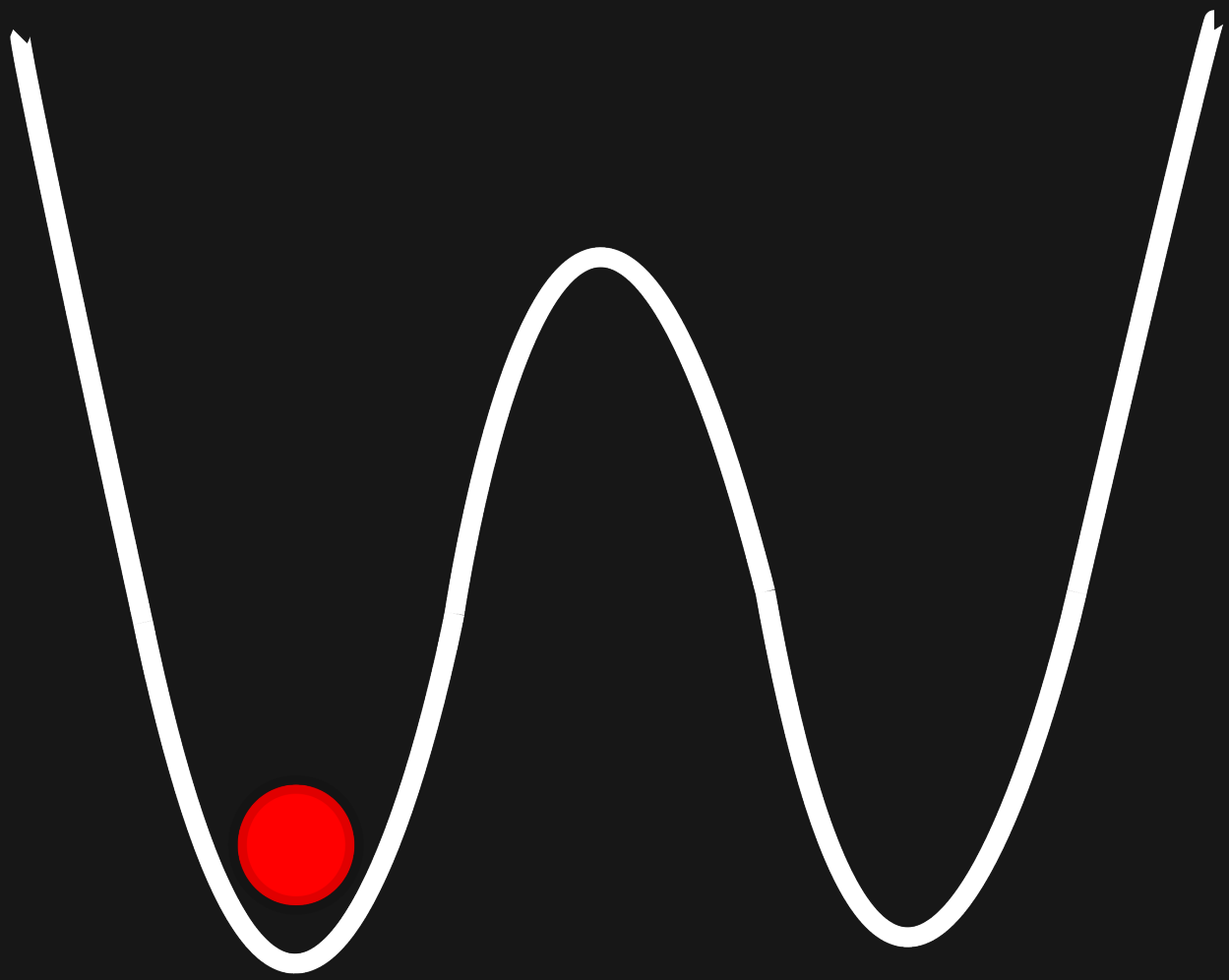
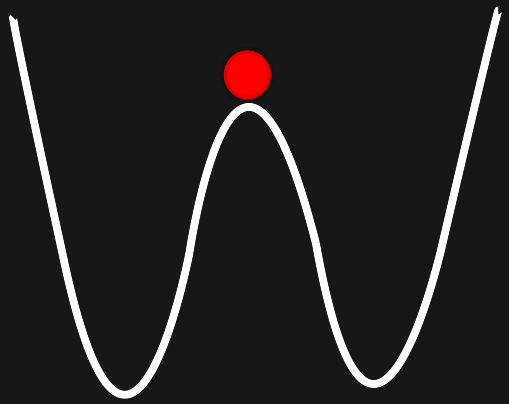
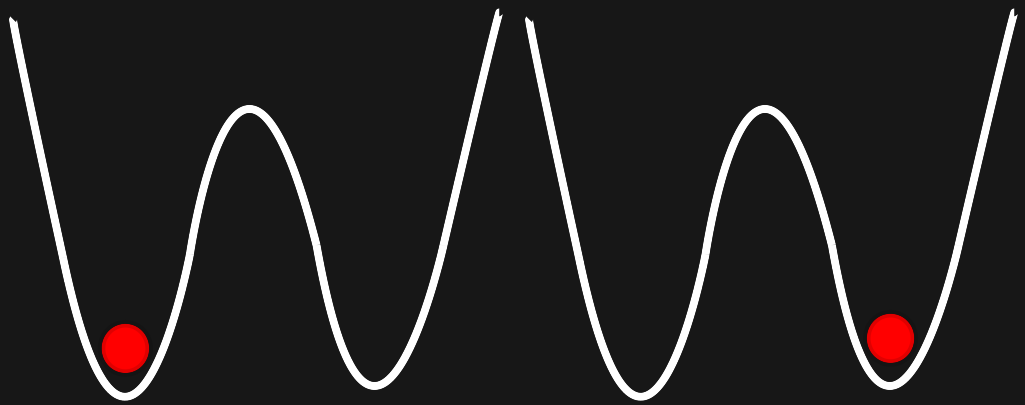


Parallel Universes



Mirror Symmetry persists in the possible outcomes.

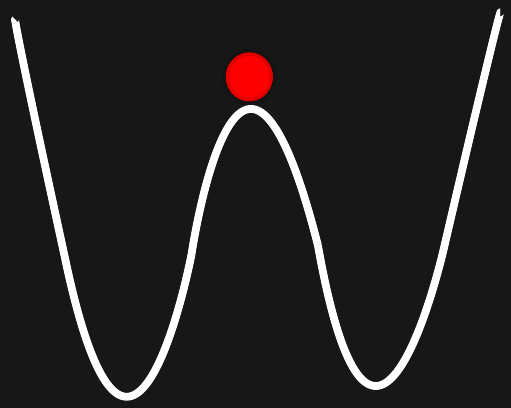


Symmetry has never been broken!

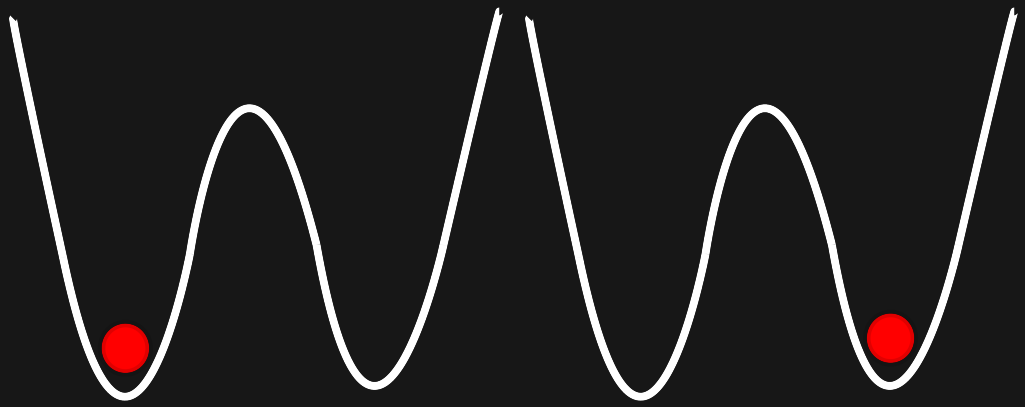
It just looks like it when we do it.

Symmetry is conserved

Symmetry is conserved at **all times.**



Existence of Parallel Universes (possible outcomes) conserves symmetry.

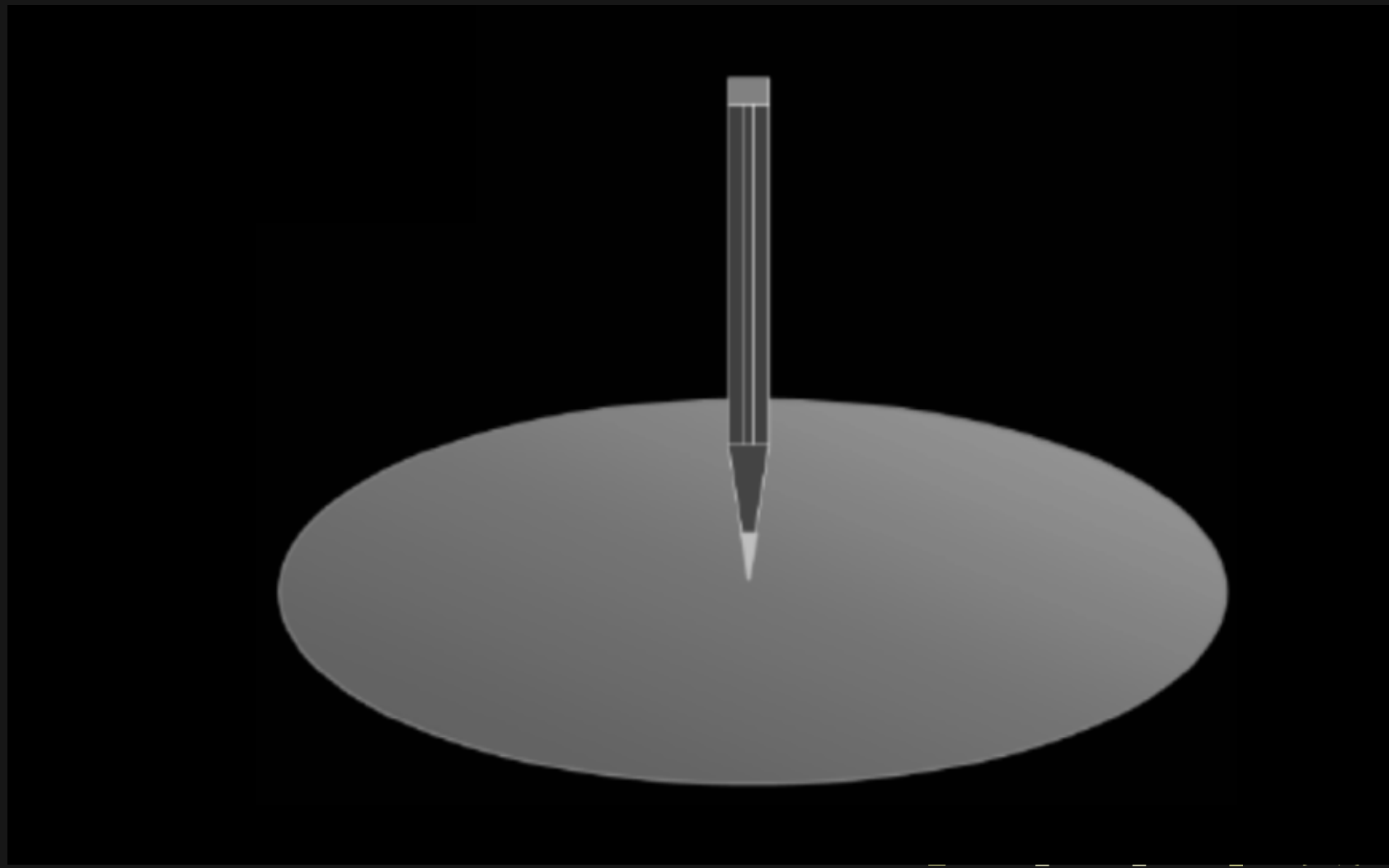


Quick Recap

- System seems to breaks symmetry by itself
- Parallel Universes restore symmetry
- Symmetry constrains our system at all points
- This phenomena is Spontaneous Symmetry Breaking (SSB)

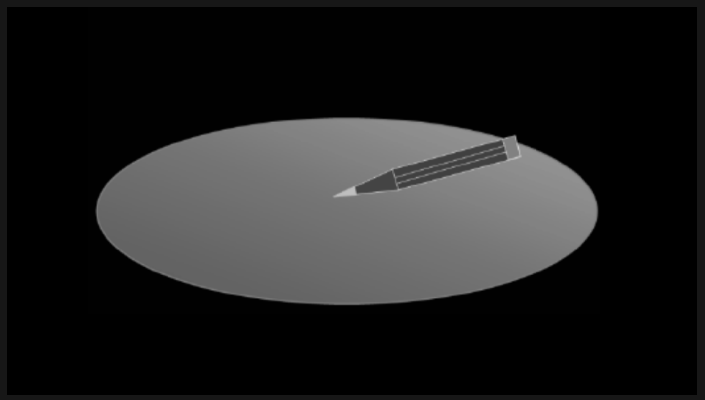
Another SSB example!

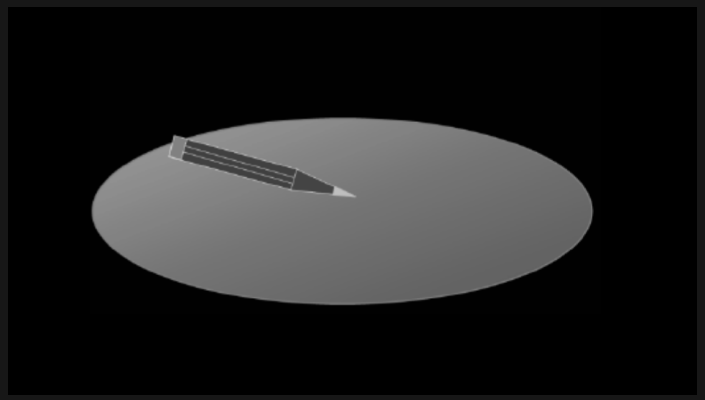
Pencil Standing, Azimuthal Symmetry. Falls Down



Another SSB example!

Pencil Standing, Azimuthal Symmetry. Parallel Universes:

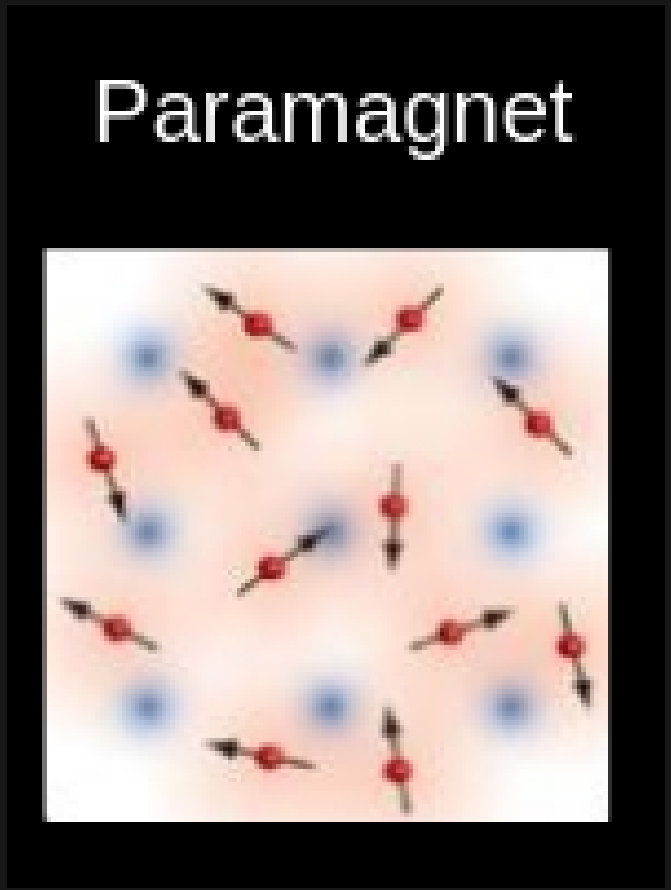




Parallel Universe for every angle $\theta \in (0, 2\pi]$.

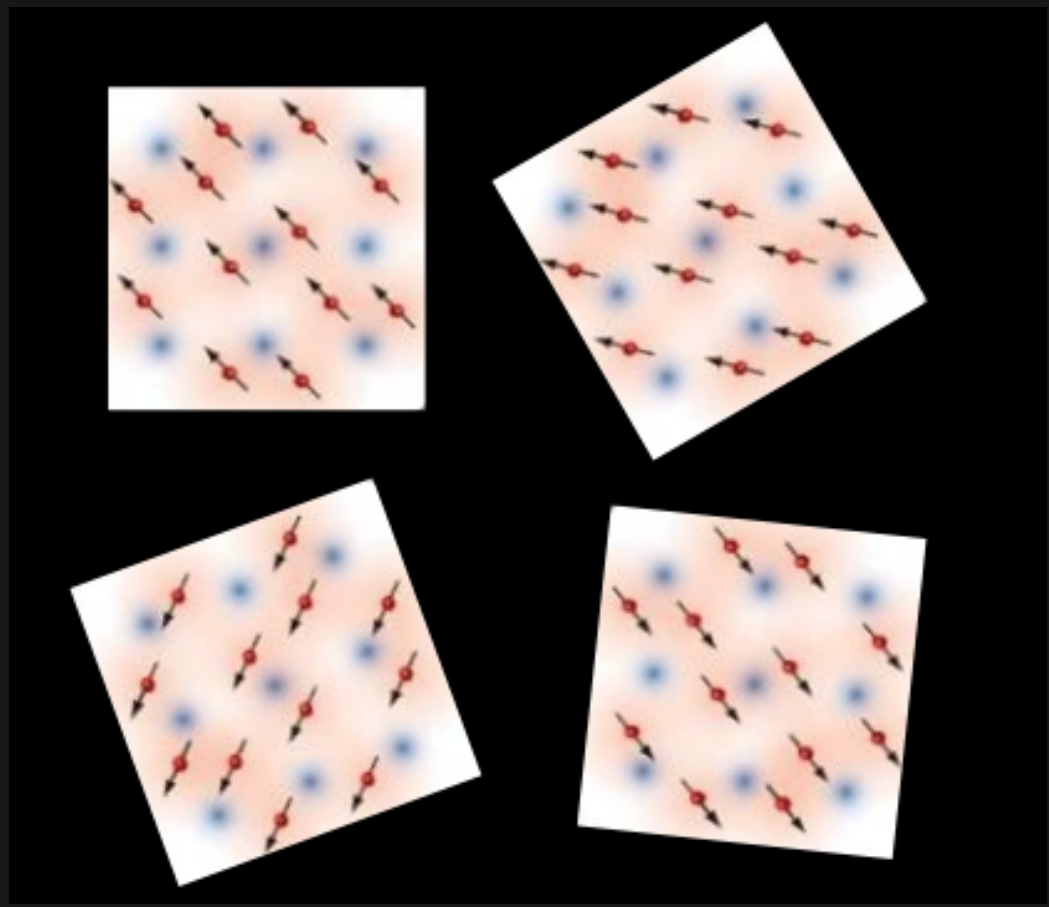
Another SSB example!

Paramagnet, 3D rotation symmetry



Another SSB example!

Pencil Standing, Azimuthal Symmetry. Parallel Universes:



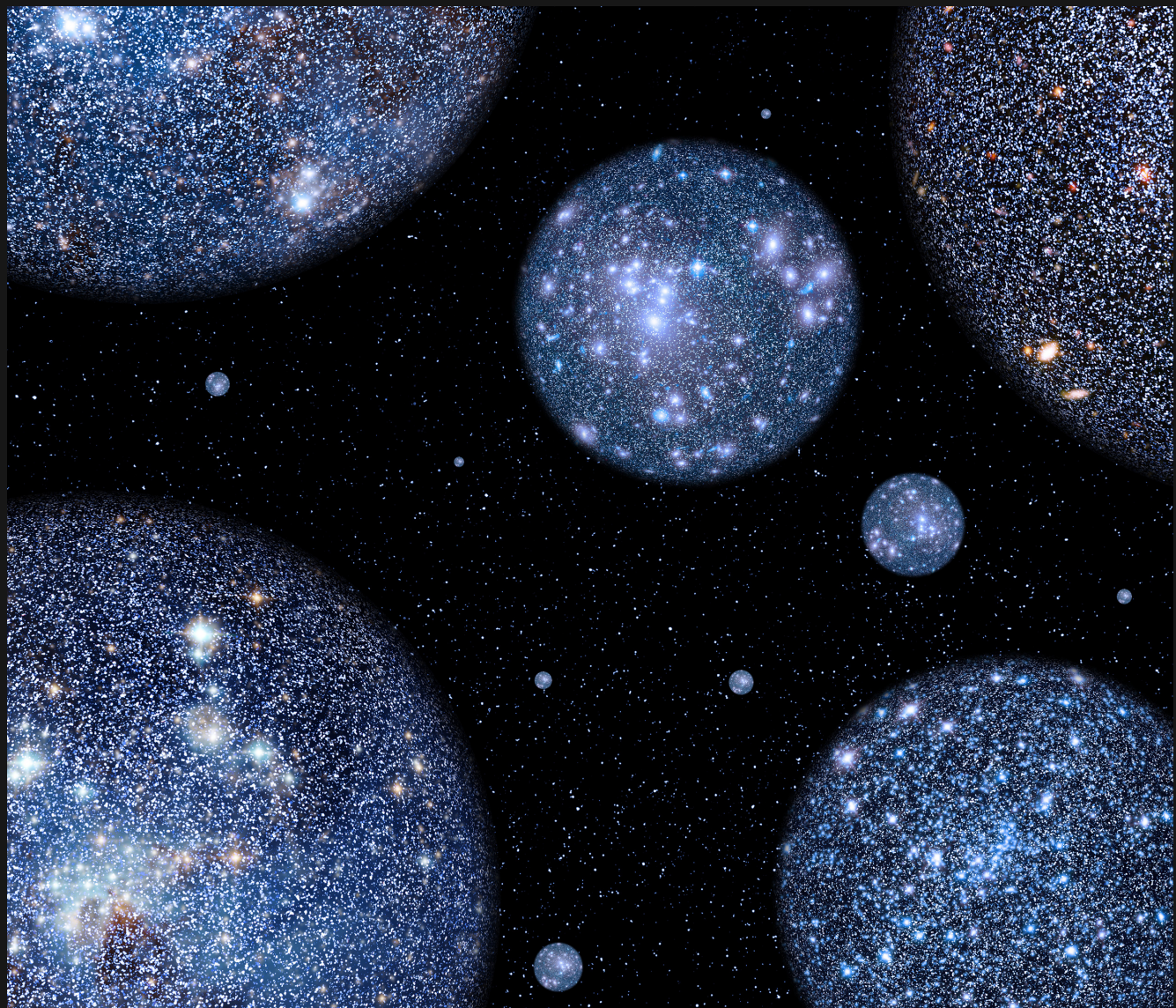
Parallel Universe for every $\theta \in (0, 2\pi]$ and $\phi \in (0, \pi]$.

Quick Recap

- Symmetry describes our Universe well
- Symmetry describes many systems well
- Symmetry seems to break in many places
- Parallel Universes are everywhere!

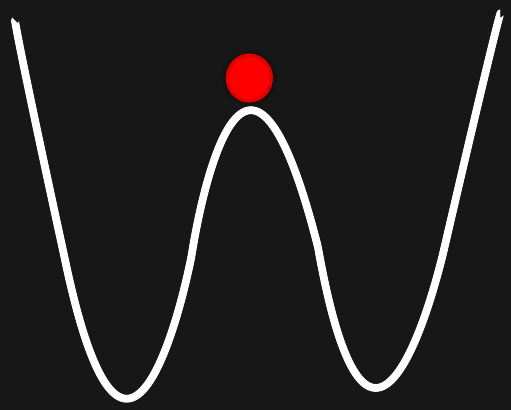
Parallel Universes

What does it look like?

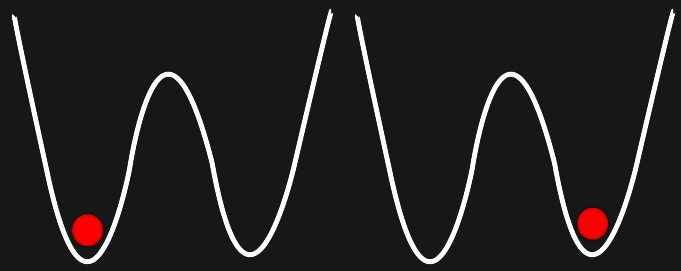


Stability of Parallel Universes

Picture a small human in the ball.



When symmetry breaks, we become rigid, stable.



Deep in one of the potential valley, the other is **virtually** unreachable.

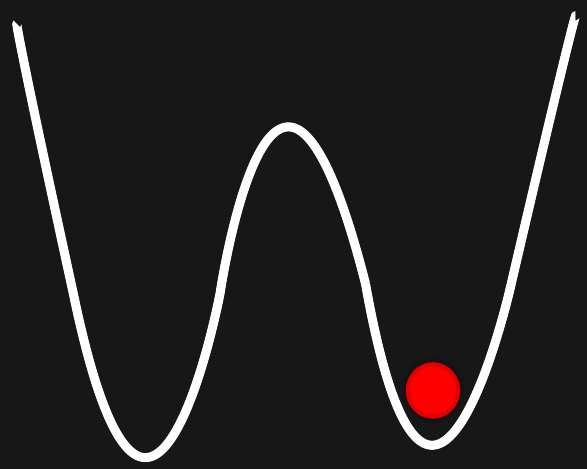
Applications

- How Paramagnets become Ferromagnets
- How Liquids become Gas
- How the Universe settled
- How electroweak force splits into Electric Force and Weak Force
- Essential in Higgs Mechanism
- Almost all modern systems in research

Each Parallel Universe looks different.

Moving between the Universes

How do we move?

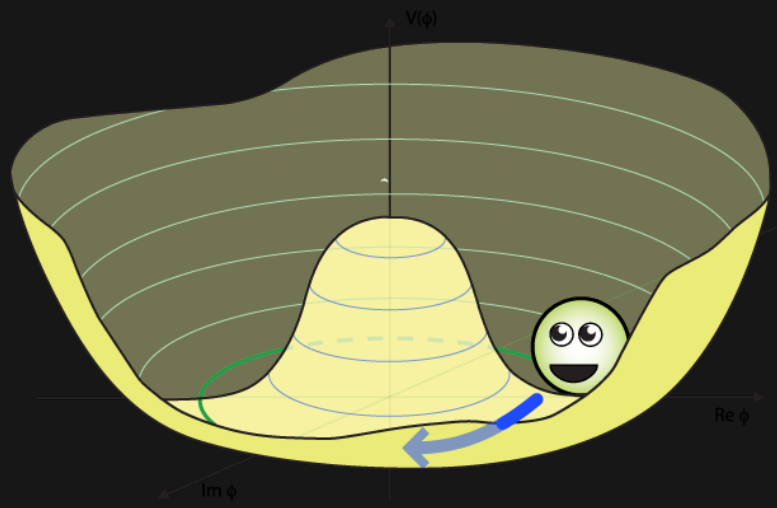


- Change our perspective
- Make an explosion

A lonely Universe

> *To go from one [Parallel Universe] to another would require changing the directions of an infinite number of dipoles, an impossible task for the finite little man*

But don't go bombing things to see the universe!!!
We can't... Probably? At least likely not intentionally.



But why tho

Good for fun and midnight conversations and philosophical musing.

The Paradigm of symmetry

Since Landau's work in the 40's, symmetry is at the center of describing the world in physics.

- Universality Classes
- Criticality at symmetry breaking transitions
- Topological transitions (non-symmetry breaking)

Classification can help us systematically study systems and their *excitations.*

How to learn more:

The Paradigm of symmetry

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- Universality Classes
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Classification can help us systematically study systems and their *excitations.*

How to learn more: Get Good

Thank you!

Search Friendly words

- Lev Landau
- Emmy Noether (Noether's Theorem)
- Spontaneous Symmetry Breaking
- Criticality
- Topological transitions

Examples:

- Ferromagnet (Ising, XY, O(N), Potts, Heisenberg model)
- Liquid -Gas Transition
- Higgs Mechanism
- Chiral Symmetry breaking
- Electroweak Symmetry breaking

Excitations