Symmetry of Nature and Nature of Symmetry

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FZÚ AV ČR, Na Slovance 1999/2 Praha 8

Newton's laws

- Motion occurs because of external forces acting on an object which directly determines the acceleration
- **How does a particle move?**
  Why does a particle move?

$$F = ma$$

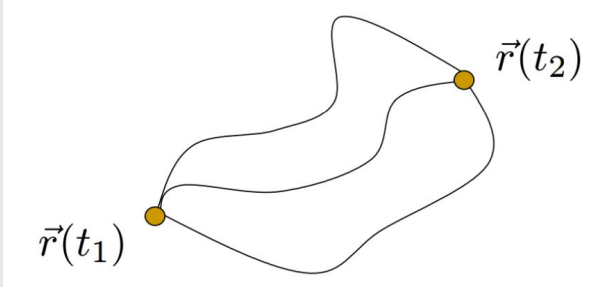
twitter.com @Newtons_Gravity [online].[cit. 2018-02-01]. Available from: https://twitter.com/newtons_gravity

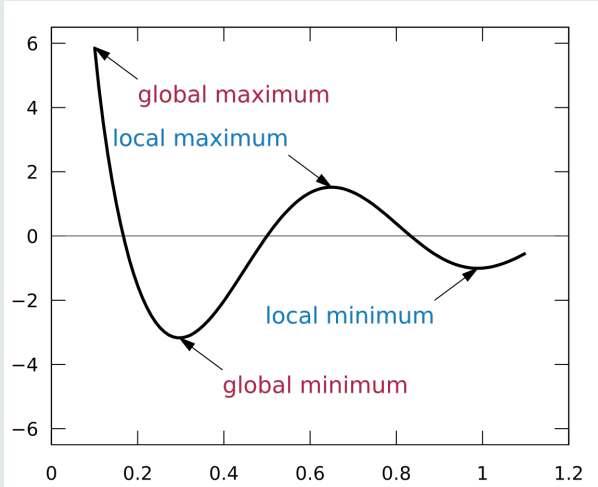
Action principle

- To each possible path, we assign a number called action
- Action is determined by a function of position and velocity called a **Lagrangian**

$$L = K.E - P.E$$

- The path followed by a classical particle will be such that the action is an extremum (maximum or minimum)

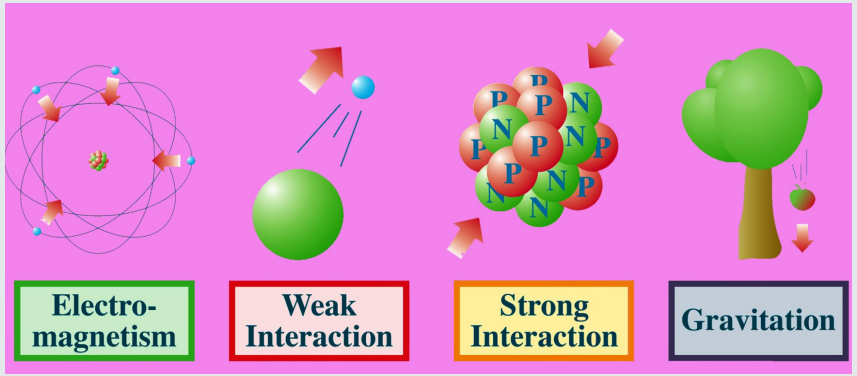




statinfer.coms[online].[cit. 2022-06-22]. Available from: https://statinfer.com/204-5-10-local-vs-global-minimum/

Why use action principle over Newton's laws

- AP can use any coordinate system
- Describes **all known forces**: gravity, electromagnetism, strong and weak force
- Is at the heart of quantum mechanics

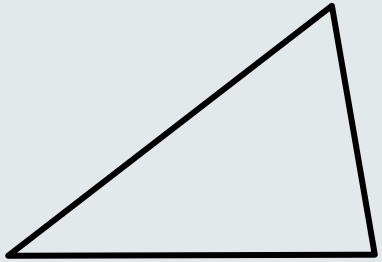


Informationpalace.com [online]. [cit. 2020-10-23]. Available from: https://www.informationpalace.com/forces-of-nature/

Symmetry

Maths:

“One shape is identical to the other shape when it is moved, rotated, or flipped”



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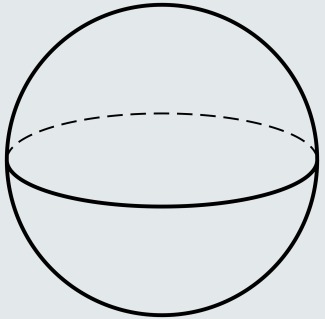

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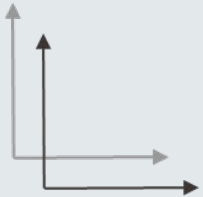
Symmetry

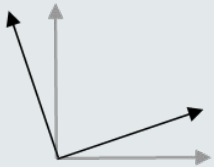
Physics:

“A transformation, either of the degrees of freedom or other parameters, such that the action under these transformation does not change”

Continuous Symmetry

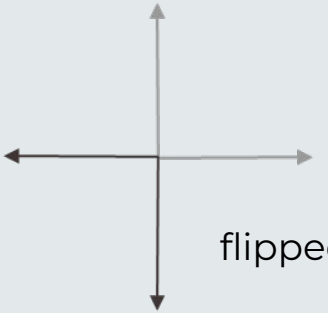


shifted



rotated

Discrete Symmetry



flipped

Noether's Theorem

Continuous symmetry of action	Conserved quantity

Examples

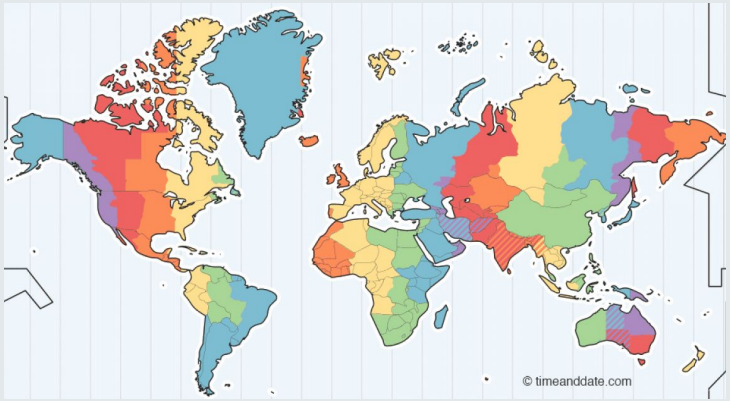
Translational symmetry	Linear momentum
Rotational symmetry	Angular momentum

Wikipedia [online]. [cit. 2022-06-21]. Available from: https://cs.wikipedia.org/wiki/Emmy_Noetherov%C3%A1

Noether's Theorem and Time

- Newtonian mechanics
  - clocks tick at the same rate
  - t=0 is arbitrary
  - time translation invariance

Time-translation symmetry ⟷ Conservation of total energy

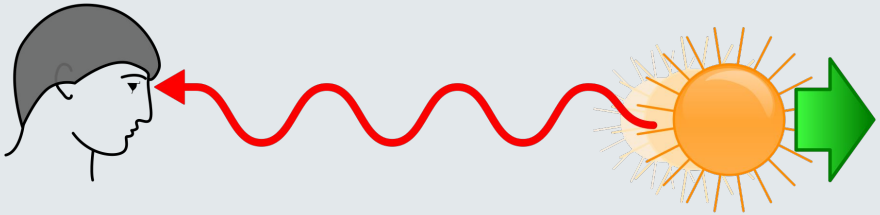


Time and date [online]. [cit. 2022-06-21]. Available from: https://www.timeanddate.com/time/map/

Noether's Theorem and Time

- Time began with the Big Bang
- Nature has a preferred t=0

  ⇒ Total energy of the Universe is **not conserved**



Wikipedia [online]. [cit. 2022-06-21]. Available from:
https://en.wikipedia.org/wiki/Redshift#/media/File:Redshift_blueshift.svg

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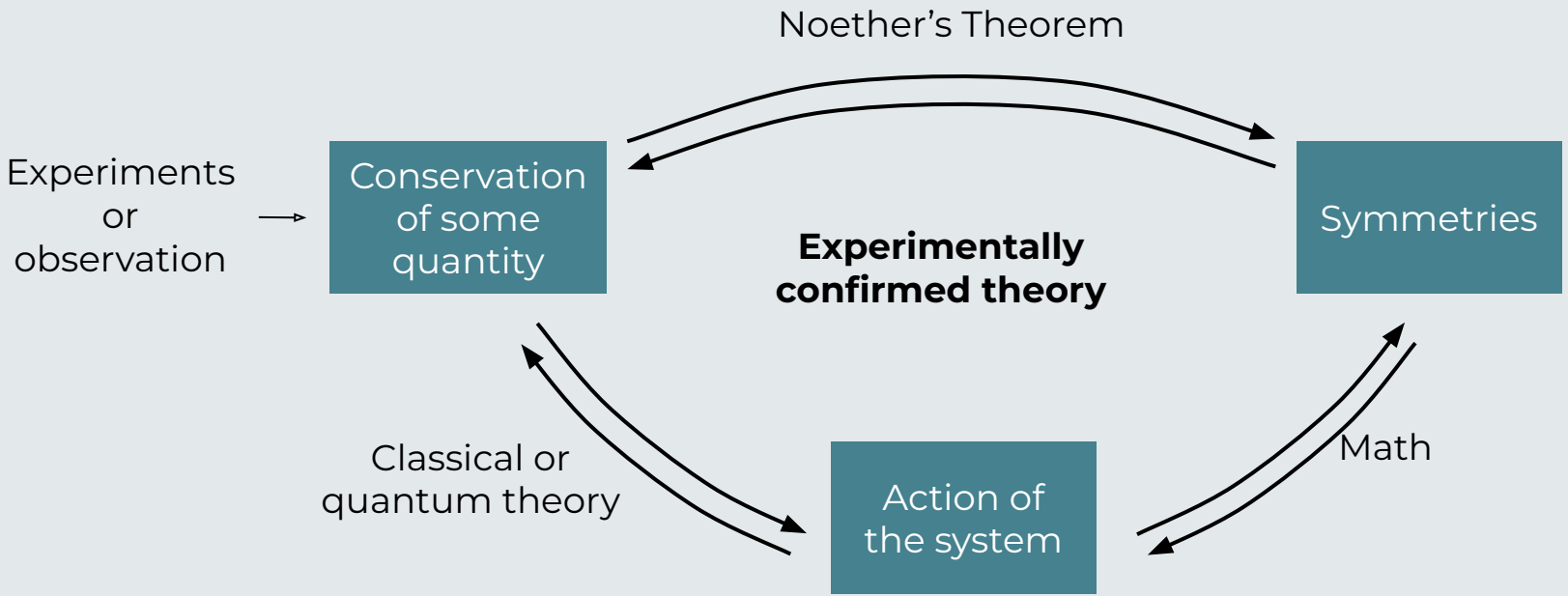
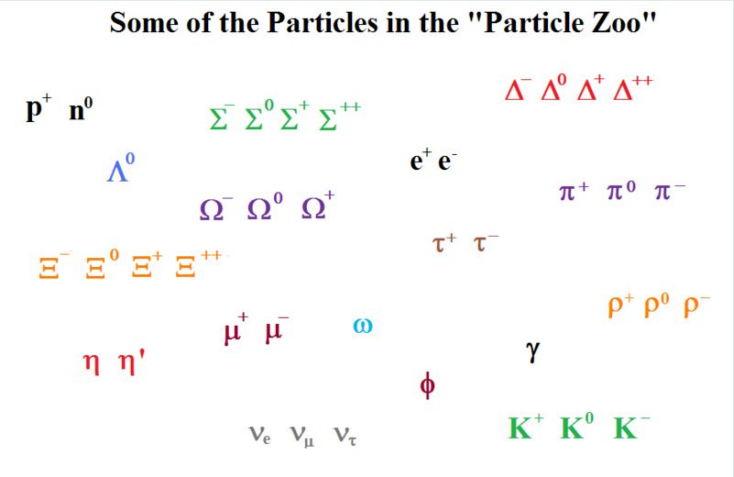
Action paradigm



How symmetry shaped standard model

- 1950s - “Particle Zoo”
- Symmetry helped us to organize the particles

  Only a few are fundamental
- All predicted particles were matched with experiments by the 1980s



Wikipedia [online]. [cit. 2022-06-21]. Available from: https://commons.m.wikimedia.org/wiki/File:The_Particle_Zoo.png

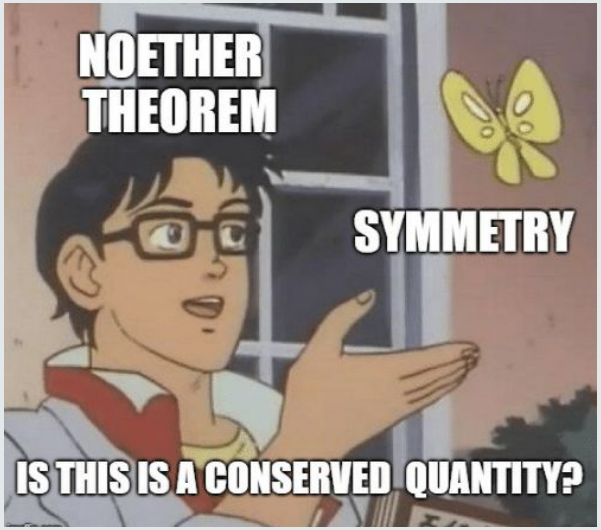
Conclusion

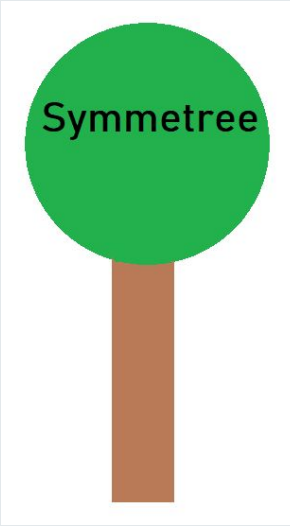
- Action principle and symmetry are at the heart of physics
- Standard model is not the end!
- *Maybe one day we go beyond the action principle…*

Listverse [online]. [cit. 2022-06-21]. Available from: https://listverse.com/wp-content/uploads/2013/04/Screen-Shot-2013-04-21-at-9.15.57-PM.jpg

Thank you for your attention!

(please check out our amazing paper) 👉👈





On a scale of 1 to 10, how much we love symmetry?

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