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With our own eyes we can observe the world...



and understand many of the laws of physics.



However, our resolution is limited by the wavelength (or frequency or energy) of the light that our eye can see.



shorter wavelength (or higher frequency or higher energy) carries information that our eye can't perceive, revealing the equally wonderful quantum world.



#### Not just light!

**Quantum Mechanics:** All particles have wave properties.

**Theory of Relativity: E = mc<sup>2</sup>** Mass is a form of energy. With sufficient energy density we may produce particles.



Louis de Broglie (1892 - 1987)

#### Thermodynamics: E ~ kT

With sufficient energy with can study temperature conditions similar to those right after the Big Bang.





#### Not just light!

**Quantum Mechanics:** All particles have wave properties.

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Albert Einstein (1879 - 1955)

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#### Not just light!

#### **Quantum Mechanics:** All particles have wave properties.

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Ludwig Boltzmann (1844 - 1906)



#### Thermodynamics: E ~ kT

With sufficient energy with can study temperature conditions similar to those right after the Big Bang.



The branch of physics dedicated to these studies is High-Energy Physics.

And the dominant theory of elementary particles and their interactions is called the "Standard Model".











and is the base of chemistry, biology, and therefore, life itself.









# A force is mediated by a force-carrier boson.

- Applied on particles with electric charge.
- Mediated by photons.
- Infinite range.
- Decreases with distance.
- Described by Quantum Electrodynamics.











# **Strong Interaction**





# **Strong Interaction**

- Applied only to quarks.
- Mediated by gluons.
- Increases with distance.
- Described by Quantum Chromodynamics.





# **Strong Interaction**

Trying to separate the quarks of a meson:





### Weak Interaction





### Weak Interaction

- Mediated by the heavy W<sup>+</sup>, W<sup>-</sup>, Z bosons
- Described by the Quantum theory of weak interaction

It can change the flavor of a particle



and it is necessary for the nuclear fusion that sustain the sun.



beta radioactive decay

keeps the sun alive, and therefore, us.



Dominant in the large scale, however, the weakest of the known forces.

Understanding gravity in the quantum scale is one of the open subjects of High Energy Physics!





# Unification of forces

# Unification of Quantum Electrodynamics and the Quantum theory of the weak interaction.







1979 Nobel Prize in Physics

Sheldon Lee Glashow

Abdus Salam

Steven Weinberg

The unified theory described experimental results, and predicted:

- the **photon** ( $\gamma$ ) as mediator of electromagnetism,
- the W bosons as the mediator of the weak interaction,
- along with the **Z boson** for which there was no experimental evidence.



# Unification of forces

#### The Gargamelle experiment at CERN

was set up to observe weak interactions mediated by the Z boson.





# Unification of forces

#### The discovery of the Z boson came in 1973.



#### Direct observation of the W and Z bosons followed with the **UA1** and **UA2** experiments at CERN (1981-1990)



Simon van der Meer and Carlo Rubbia (1984 Nobel Prize in Physics)



## Particle mass and the Higgs boson

The final requirement to establish the Standard Model of particle physics is that the mass of every particle is zero,





# Particle mass and the Higgs boson



2013 Nobel Prize in Physics

Robert Brout $^{\!\scriptscriptstyle(+)}\!,$  François Englert and Peter Higgs

The theory was completed by introducing the Brout-Englert-Higgs (BEH) field.

- the interaction of particles with the BEH field is their mass
- the quantum of the BEH field is the Higgs boson



discovered by the **ATLAS** and **CMS** experiments in 2012.



There is a series of unanswered questions, such as:



- Quantum theory of gravity?
- What is **dark matter** (27% of the universe) and **dark energy** (68% of the universe)?



## Inventions at CERN

#### Invention of the world-wide-web

by the British physicist Sir Tim Berners-Lee, in 1989,



to allow information sharing between scientists around the world.



## Inventions at CERN



#### **Development of the first transparent**

**touchscreen** by the Danish engineer Bent Stumpe and the British computer scientist Dr. Frank Beck,

for the CERN SPS Control Room.



## Inventions at CERN

**The Worlwide LHC Computing Grid (WLCG)** combines the computing resources of about 900 000 computer cores from over 170 sites in 42 countries, producing a massive distributed computing infrastructure.





**The ENLIGHT network** was established in 2002 to coordinate European efforts in **hadron therapy**, and today has more than 700 participants from 25 European countries.



