MATH431

Lecture 0

2020–2021

Semester 2

Overview:

- Brief glance of the basic concepts and structures that underlie modern particle physics. Much of the module will be devoted to the details of these basic structures and concepts. We will try to understand not only what they are, but also how they developed from earlier classical theories.
- Physics : Mathematical modelling of experimental observations. Predict outcomes of experiments.
- Initial conditions : Mathematical model $\rightarrow$ Predicted outcome $\leftrightarrow$ Experimental data
- Practical : An acceptable mathematical model is the one which is most successful in accounting for a wide range of experimental observations

Themes

- Themes: Reductionism : Large to small

  Celestial, Atomic, Nuclear, sub–nuclear, ...

- Themes: Unification :
  - Newton unified mechanics in the Earth & Skies
  - Faraday & Maxwell unified Electric & Magnetic forces
  - Einstein unified Mechanics & ElectroMagnetism in special relativity
  - Glashow–Weinberg–Salam Weak & EM forces
  - Georgi–Glashow ElectroWeak & Strong
- Inventory :
  - Forces : E&M, Weak, Strong: spin $+1$ particles
    $U(1)$ $SU(2)$ $SU(3)$
    Gravity: spin $+2$ particle
  - Particles :
    - Quarks & leptons
      Strong not strong

Quarks	$\begin{pmatrix} \text{up} \\ \text{down} \end{pmatrix}$	$\begin{pmatrix} \text{charm} \\ \text{strange} \end{pmatrix}$	$\begin{pmatrix} \text{top} \\ \text{bottom} \end{pmatrix}$
Leptons	$\begin{pmatrix} \nu_e \\ \text{electron} \end{pmatrix}$	$\begin{pmatrix} \nu_\mu \\ \text{muon} \end{pmatrix}$	$\begin{pmatrix} \nu_\tau \\ \text{tau} \end{pmatrix}$

- Problems
  - mass? $\longrightarrow$ generated by the Higgs particle(?)
    observed at the LHC. Ongoing experimental studies
  - Unification: Gravity +SM ? $\longrightarrow$ Strings ?
    Hierarchy $\longrightarrow$ supersymmetry? extra dimensions?
    why is gravity so much weaker than the other forces?
  - Replication: why three generations of quarks & leptons?
    mass spectrum? mixings?
  - Reductionism: what lies beyond? LHC? Strings?
    connection with the large $\longrightarrow$ modern cosmology;
    evolution of the universe; the hot big bang.

Modern paticle physics: $\longrightarrow$ symmetry groups and their representations

Lorentz & Poincare groups; internal groups

Particles are classified by mass & spin $\longrightarrow$ labels of the Poincare group

- spin 1 $\longrightarrow$ force carriers
- spin $\frac{1}{2}$ $\longrightarrow$ fermionic matter states
- spin 0 $\longrightarrow$ scalar particles, *e.g.* Higgs
- spin 2 $\longrightarrow$ gravitational interactions

Each spin state obeys a covariant differetial equation.

solutions $\longrightarrow$ quantised fields $\longleftrightarrow$ elementary particles

interactions $\longleftrightarrow$ renormalisable potential $\longrightarrow$ predictable framework

We start with the Lorentz and Poincare groups.