Lecture 4: Discussion Topics

Discussions Topics belonging to Lecture 4

When you are assigned a topic, prepare to lead a discussion on the subject with the tutor group.
You are expected to introduce the topic, prepare a few slides or write on the board,
and be somewhat of an expert.
At the same time you do not have to know everything. You may also address questions to the tutor group.

Topic-10: Symmetry and non-observables

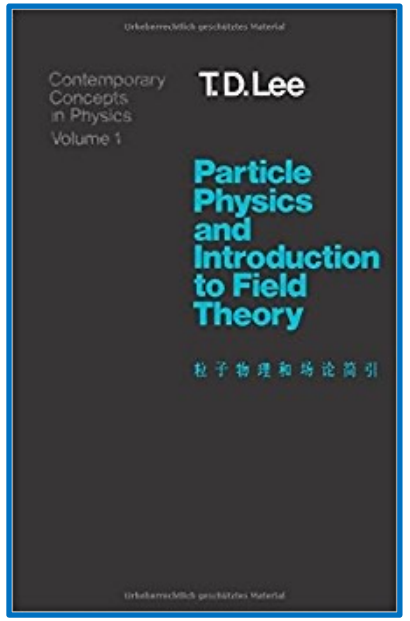
- Explain the idea behind non observables
- What are the symmetries and non-observables related to:
  - Electromagnetism
  - Weak interaction
  - Strong interaction
  - C-violation
  - P-Violation
  - T-Violation

Topic-10: Symmetry and non-observables

T.D.Lee: "The root to all *symmetry* principles lies in the assumption that it is impossible to observe certain basic quantities; the *non-observables*"

There are four main types of symmetry:

- Permutation symmetry:
  Bose-Einstein and Fermi-Dirac Statistics
- Continuous space-time symmetries:
  translation, rotation, velocity, acceleration,…
- Discrete symmetries:
  space inversion, time reversal, charge conjugation,…
- Unitary symmetries: gauge invariances:
  U_1(charge), SU_2(isospin), SU_3(color),…



⇒ If a quantity is fundamentally non-observable it is related to an *exact* symmetry

⇒ If it could in principle be observed by an improved measurement; the symmetry is said to be *broken*

Noether Theorem: symmetry ⟺ conservation law

Topic-10: Symmetry and non-observables

Non-observables	Symmetry Transformations	Conservation Laws or Selection Rule
Difference between identical particles	Permutation	B.-E. or F.-D. statistics
Absolute spatial position	Space translation: $\vec{r} \to \vec{r} + \vec{\Delta}$	momentum
Absolute time	Time translation: $t \to t + \tau$	energy
Absolute spatial direction	Rotation: $\vec{r} \to \vec{r}'$	angular momentum
Absolute velocity	Lorentz transformation	generators of the Lorentz group
Absolute right (or left)	$\vec{r} \to -\vec{r}$	parity
Absolute sign of electric charge	$e \to -e$	charge conjugation
Relative phase between states of different charge Q	$\psi \to e^{i\theta Q}\psi$	charge
Relative phase between states of different baryon number B	$\psi \to e^{i\theta N}\psi$	baryon number
Relative phase between states of different lepton number L	$\psi \to e^{i\theta L}\psi$	lepton number
Difference between different coherent mixture of p and n states	$\begin{pmatrix} p \\ n \end{pmatrix} \to U \begin{pmatrix} p \\ n \end{pmatrix}$	isospin

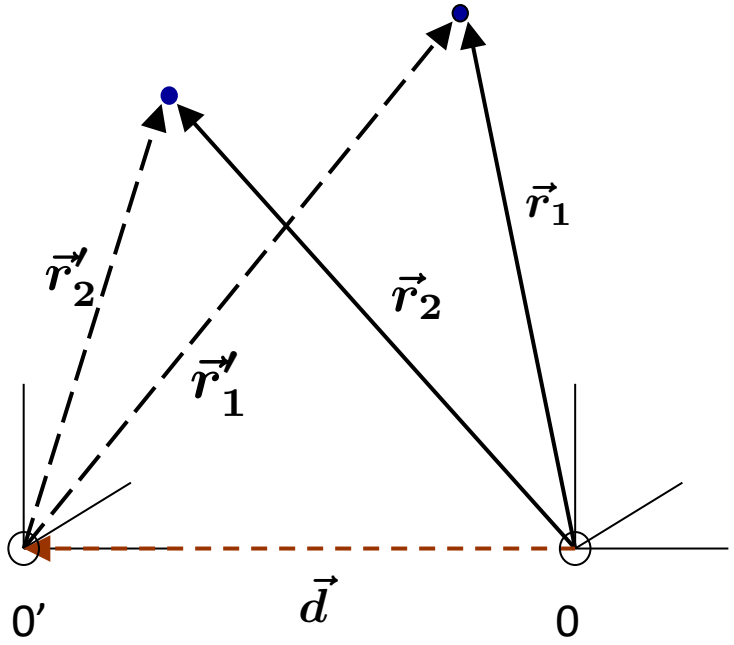
Topic-10: Symmetry and non-observables: example

- Simple example: potential energy V between two charged particles:

Absolute position is a non-observable:
The interaction is independent on the choice of the origin 0.

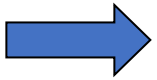
Symmetry:
V is invariant under arbitrary space translations:

$$\vec{r_1} \to \vec{r_1} + \vec{d} \qquad \vec{r_2} \to \vec{r_2} + \vec{d}$$



Consequently:

$$V = V\left(\vec{r}_1 - \vec{r}_2\right)$$



Total momentum is conserved:

$$\frac{d}{dt}\underbrace{\left(\vec{p}_1 + \vec{p}_2\right)}_{\vec{p}_{\mathrm{tot}}} = \vec{F}_1 + \vec{F}_2 = -\left(\vec{\nabla}_1 + \vec{\nabla}_2\right) V = 0$$

Topic-11: Broken symmetries

a) What do you think is the difference between an exact and a broken symmetry?

b) Can you explain the name *spontaneous* symmetry breaking means?

c) Which symmetry is involved in the gauge theories below? Which of these gauge symmetries are exact? Why/Why not?

   i. U1(Q) symmetry
   ii. SU2(u-d-flavour) symmetry
   iii. SU3(u-d-s-flavour) symmetry
   iv. SU6(u-d-s-c-b-t) symmetry
   v. SU3(colour) symmetry
   vi. SU5(Grand unified) symmetry
   vii. SuperSymmetry