# Kern- und Teilchenphysik II Exercise Sheet 1

HS 16
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`http://www.physik.uzh.ch/de/lehre/PHY213/FS2017.html`

Issued: 09.03.2017
Due: 22.03.2017

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**Exercise 1:** Conservation laws (4.5 Pts.)

One other quantum number that we did not discuss is Izospin. The izospin is a symmetry that you can exchange the quarks $u$ and $d$ without changing the strong interactions. Historically it was introduced by Heisenberg to "unify" proton and neutron. Both of them have the izospin $I = \frac{1}{2}$. The 3rd component of the izospin are however different: $I_3 = \pm\frac{1}{2}$. The strong interactions conserve the $I$ and the $I_3$[1]. The EM interactions conserve the $I_3$ component but not the $I$. The weak iterations do not conserve both the $I$ and the $I_3$.

In summary Tab. 1 presents the quantum numbers and which iteration conserves them.

| Quantum Number | Strong int. | EM int. | Weak int. |
|---|---|---|---|
| Charge Q | Y | Y | Y |
| Baryon Number B | Y | Y | Y |
| Lepton number L | Y | Y | Y |
| Lepton family/flavour number $L_i$ | Y | Y | Y |
| Izospin I | Y | N | N |
| 3rd component Izospin $I_3$ | Y | Y | N |
| S,C,B,T | Y | Y | N |
| Parity P | Y | Y | N |
| Charge conjugate C | Y | Y | N |
| CP, T | Y | Y | N $\mathcal{O}(10^{-3})$ |

Table 1: Conservation of quantum numbers for different forces. Y=YES, N=NO.

Based on the table above please indicate which forces is responsible for which interaction:

- $\pi^- p \to \pi^- \pi^+ n$
- $\gamma p \to \pi^+ n$
- $\nu_\mu n \to \mu^- p$
- $\pi^0 \to e^- e^- e^+ e^+$
- $p\bar{p} \to \pi^- \pi^+ \pi^0$
- $\tau^- \to \pi^- \nu_\tau$

[1] This is valid up to quark mass effects.

- $D \to K^+\pi^-\pi^+$
- $\pi^- \to \pi^0 e^- \nu_e$
- $\Lambda_0 p \to K^- pp$

**Exercise 2:** Conservation laws 2 (2 Pts.)

Show that mezon that decays to a pair $\pi^+\pi^-$ via strong interactions has $C = P = (-1)^J$, where J is the total angular momentum.

**Exercise 3:** Conservation laws 3 (4 Pts.)

We know that mezons $f_2(1275)$ $(J = 2)$ and $\rho(769)$ $(J = 1)$ are decaying via strong interactions to two charged pions. Which of the processes is inpossible in the EM interactions: $\rho \to \pi^0\gamma$ or $f_2^0 \to \pi^0\gamma$. Which of the decays is forbidden in all interactions: $\rho \to \pi^0\pi^0$, $f_2 \to \pi^0\pi^0$.

**Exercise 4:** Conservation laws 4 (2 Pts.)

We have proton and antiproton in the S state. Why reaction of $p\bar{p} \to \pi^0\pi^0$ cannot proceed via strong interactions?

**Exercise 5:** Pion decay (16 Pts.)

Please calculate the matrix element of the dacay $\pi^- \to \mu\nu_\mu$. The form factor for the pion has the form of $F^\mu = p_\mu f_\pi$, where $f_\pi$ is so called pion decay constant and is calculated on lattice to be $f_\pi = 130$ MeV. Using the matrix element calculate the $\Gamma$. Calculate also the $\Gamma$ for the $\pi^- \to e\nu_e$. Why is the electron mode different then the muon one?

**Exercise 6:** Muon decay (16 Pts.)

Calculate the matrix element for the dacay of the muon: $\mu^- \to e^-\nu_\mu\bar{\nu}_e$. Using "Golden Rule" calculate the calculate the $\Gamma$ and the lifetime of the muon.

**Exercise 7:** Muon decay simulation (12 Pts.)

Please simulate the muon decay from exercise 6 using ROOT. Please assume for the moment flat phase space (aka matrix element =1). The example can be found:

`https://root.cern.ch/root/html/tutorials/physics/PhaseSpace.C.html`

having simulate this decay please calculate the electron energy in the muon central of mass and draw it for your simulated events. Simulate at least 100.000 events.