8.2 Spontaneous symmetry breaking

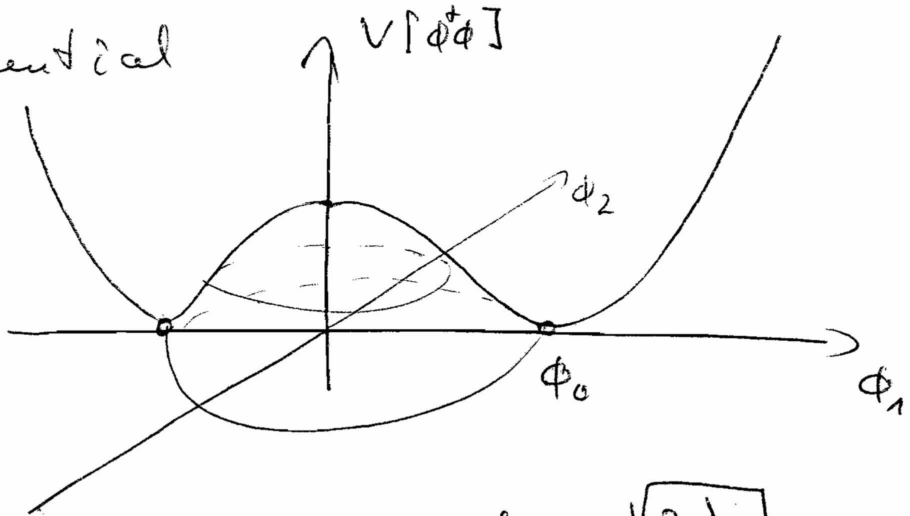
The gauge bosons of the weak force are massive, $Z, W^\pm \sim 10^2\,\mathrm{GeV}$.

Mass terms for the gauge fields <u>break</u> gauge invariance! Way out: spont. symm. breaking, Higgs mechanism

$$S_{Higgs}[A_\mu, \phi] = (D_\mu \phi)^\dagger (D_\mu \phi) \left. \begin{array}{l} + \mu^2 \phi^\dagger \phi \\ - \lambda (\phi^\dagger \phi)^2 \end{array} \right\} -V \tag{8.19}$$

with $A_\mu \in u(1) \times su(2)$

Potential



$$\phi_0 = \sqrt{\frac{2\lambda}{\mu^2}}$$

The minimum is at a non-trivial field expectation value, e.g. $\langle \phi \rangle = \phi_0$

[Strictly speaking this is valid for

$$V = \lambda (\phi^+ \phi)^2 - \mu^2 \phi^+ \phi - \varepsilon \phi_0 \qquad (8.20)$$

with $\varepsilon \to 0$]

Expanding about ϕ_0 : $\phi = \phi_0 + \delta\phi$ leads to ($\partial_\mu \phi_0 = 0$)

$$(D_\mu \phi)^+ (D^\mu \phi) = \underbrace{A_\mu \phi_0 A^\mu \phi_0}_{\text{mass-term for gauge field}} + \delta\phi\text{-terms} \qquad (8.21)$$

Matter sector:

$$h \bar{\Psi} \phi \Psi + h.c. = 2h \bar{\Psi} \phi_0 \Psi + \delta\phi\text{-terms} \qquad (8.22)$$

mass-term for fermions

⇒ Higgs mechanism provides masses for gauge bosons & quarks, leptons

Remark:

In the Standard model only the left-handed spinors transform under the weak gauge group: $\Psi_L \to U \Psi_L$

$$\Psi_R \to \Psi_R$$

$$\phi \to U\phi$$

Hence, gauge-invariant mass terms have the form

$$\Psi_R \, \phi^+ \, \Psi_L + \text{h.c.}$$

[see e.g. Standard model lecture script 5.2 Higgs sector]