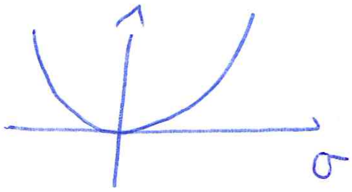
CONDENSATION

TWO IMPORTANT POINTS ABOUT CONDENSATION:
- CONDENSATION
- FLUCTUATION AROUND THE CONDENSATION

- The "condensation" itself means nothing...

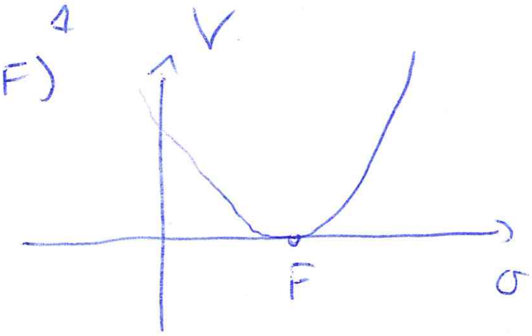
(1) $V(\sigma) = \frac{1}{2} m_\sigma^2 \sigma^2 + \frac{\lambda}{4} \sigma^4$



Minimum for $\sigma = 0$. Mass m_σ. Scattering: λ.

- Now, suppose I give you

(2) $V(\sigma) = \frac{1}{2} m_\sigma^2 (\sigma - F)^2 + \frac{\lambda}{4} (\sigma - F)^4$



Now, I have a condensate...

$\sigma = F$!!!

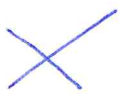
But, how can I see it physically? NO WAY!!!

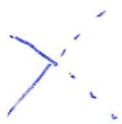
m_σ is the mass, λ the scattering!!!

Theories (1) and (2) are perfectly identical. The emergence of the condensate in the second case is an artifact of the choice of the y-axis... (ref. frame choice)!

Hence, things change drastically, if we add another field (another or add. (real) scalar field)

(1) $V_1 = \frac{1}{2} m_\sigma^2 \sigma^2 + \frac{\lambda}{4}\sigma^4 + c\sigma^2\varphi^2$

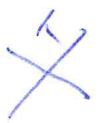
m_σ 

$m_\varphi = 0$ 

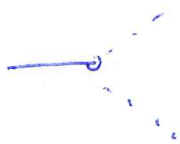
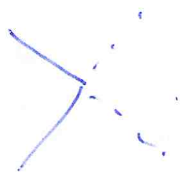
(2) $V_2 = \frac{1}{2} m_\sigma^2 (\sigma - F)^2 + \frac{\lambda}{4}(\sigma - F)^4 + c\sigma^2\varphi^2$

$\sigma \mapsto F + \sigma$

$V_2 = \frac{1}{2} m_\sigma^2 \sigma^2 + \frac{\lambda}{4}\sigma^4 + cF^2\varphi^2 + 2cF\sigma\varphi^2 + c\sigma^2\varphi^2$



m_σ

$m_\varphi = 2F^2$  

(2) $\neq$ (1)

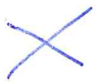
(3) $V = \frac{1}{2} m_\sigma^2 (\sigma - F)^2 + \frac{\lambda}{4}(\sigma - F)^4 + c(\sigma - F)^2(\varphi - F)^2$

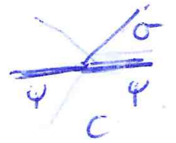
then the minimum is for $\sigma = F, \varphi = F \mapsto$ shift of both $\sigma \mapsto F + \sigma$, $\varphi \mapsto F + \varphi$

(3) = 1 (Both fields condense, but you do not see that...)

Now, things change drastically if we add another field (such as a fermion field)!

(1) $V_1(\sigma) = \frac{1}{2} m_\sigma^2 \sigma^2 + \frac{\lambda}{4} \sigma^4 + c\sigma \bar{\psi}\psi$

$m_\sigma, \lambda,$ 

$m_\psi = 0,$ 

c dimensionless...

(2) $V_2(\sigma) = \frac{1}{2} m_\sigma (\sigma - F)^2 + \frac{\lambda}{4} (\sigma - F)^4 + c\sigma \bar{\psi}\psi$

$\sigma \mapsto F + \sigma$

$$V(\sigma) = \frac{1}{2} m_\sigma^2 \sigma^2 + \frac{\lambda}{4}\sigma^4 + c(\sigma + F)\bar{\psi}\psi$$

$$= \frac{1}{2} m_\sigma^2 \sigma^2 + \frac{\lambda}{4}\sigma^4 + \underline{cF\bar{\psi}\psi} + c\sigma\bar{\psi}\psi$$

m_σ, λ

$m_\psi = cF \neq 0!$ (2) is $\neq$ from (1).

(3) The interactions that arise upon condensation are the physical realisation of it...

BTW: this is exactly the way how the Higgs gives mass to the fermions of the SM. $\mapsto$ THATCHER ANALOGY!

Back to our σ-model.

(with σ and π $(N_f = 1)$)

$$V = \frac{\lambda}{4}\left(\sigma^2 + \pi^2 - F^2\right)^2 - \varepsilon \sigma$$

$\sigma \mapsto F + \sigma$

out of that we have seen that a plenty of things happen:

- $m_\sigma \neq 0$
- $m_\pi = 0$ (for $\varepsilon = 0$, otherwise $m_\pi^2 = \varepsilon/\phi$)
-  Decay occurs
-  is very small in the chiral limit (and for $K_\mu \mapsto 0$... soft limit!!!)

The "condensation" is visible in the interactions which generate, not in the value of the field itself... This is so both for the σ and for the Higgs!!!!

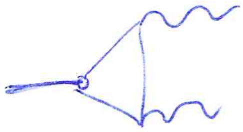
Second point:

$\pi \mapsto$ "very well known hadron"... the lightest hadron.

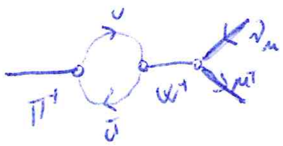
$\pi^{\pm}, \pi^0$

$\pi^+ \mapsto \mu^+ \nu_\mu$

$\quad \to e^+ \nu_e$

π^0  $\gamma\gamma$

$\pi^0 F_{\mu\nu} \tilde{F}^{\mu\nu}$ $\qquad F_{\mu\nu} = \partial_\mu A_\nu - \partial_\nu A_\mu$



Why larger than $e^+\nu_e$?

(Mixing) R-L ... the mass term is responsible for that....

$$\boxed{\Gamma \propto m_e^2}$$

... but: where is the σ? Which is the particle corresponding to the σ?

Search for the state with the corresponding quantum number...

The lightest one is the state $f_0(500)$! Is this the σ-partner of the pion? The fluctuation of the chiral condensate?

This state has a very long and difficult history.

'80 $f_0(600)$ $M_0 \simeq 400 - 1200$ MeV.

'90 $\to$ removed

'2000 $\to$ returned!

'2012 $\mapsto$ renamed $f_0(500)$ and "$450 - i\,250$" has quoted mass!

(Some

$\Rightarrow$ why the pole?

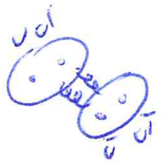
$\Rightarrow$ very broad state ...

"An unstable state does not have a properly defined mass, but has an energy distribution".

However, although the existence is "certain", the question is if this is the state we search...

Indeed, many works are in agreement that $f_0(500)$ is not $\sqrt{\frac{1}{2}}(\bar{u}u+\bar{d}d)$...

The possibilities are:



- $[u,d][\bar{u},\bar{d}]$
- $\pi\pi$ molecule (or dyn. generated enhancement)

$\Rightarrow$ The next state to look for is

$f_0(980)$

but this state couples very strongly to K... it must contain a strange quark!

Indeed, this state can be also well interpreted as a tq:

$$\sqrt{\frac{1}{2}}\left([u,s][\bar{u},\bar{s}]+[d,s][\bar{d},\bar{s}]\right)$$

$\Rightarrow$ $f_0(500)$, $f_0(980)$, $a_0(980)$, $K_0^*(800)$ $\equiv$ NONET OF TQ STATES...

... then, the next available state is the resonance $f_0(1370)$

It couples strongly to $\pi\pi$ (and less strongly to $\bar{K}K$).

it is broad...

it is "heavy"... $M_{f_0} \sim M_{f_1} \sim M_{a_1} \sim M_{f_2} \sim M_{a_2}$

Namely, recall that a "scalar" $J^{PC} = 0^{++}$ arises from

$L = 1 = S$ $\to$ similar mass than the other p-wave states.

$$M_{f_0} > M_\rho$$

$L=1$, $S=1$ $L=0$, $S=1$

what does the σ model tells us? Interesting point.

LσM $f_0(500) \to \pi\pi$ correct... This is indeed one of the reasons why $f_0(500)$ was long-time considered as such...

$\Gamma_{f_0} \approx 400$ MeV

eLσM (with VM) $f_0(500) \to \pi\pi \lesssim 150$ MeV $\Rightarrow$ too narrow!!!

This has to do with technical details... but the result is striking.

VM are there, cannot be omitted!

$\longrightarrow$

... but then:

$f_0(1370)$ → LSM (wo VM) $\quad$ 2-3 GeV

 → eLSM $\quad \approx 500$ MeV ☺ OK!!!

Indeed, we also find that $f_0(1370)$ is $\frac{1}{\sqrt{2}}(\bar{u}u + \bar{d}d)$ and is the chiral partner of the pion. Then, $f_0(1500) \approx \bar{s}s$, $f_0(1710) \approx gg$.

PDG comes to the same conclusion.

Here, care is needed:

- lattice → huge problems in the scalar sector.
- Various models and calculations ... very plausible solution ... but <u>not</u> yet confirmed.
- Mixing: