

4.1 Phases

4.2 Transitions : 1<sup>er</sup> ordre

4.3 Champ moyen

Weiss — Principe var.


4.4 Fonctionnelle G.L.

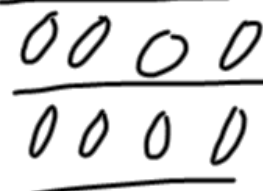
4.5 Universalité exposants  
critiques. (Critère de  
Ginzburg)

## 4.1 Phases, états, symétries brisées

- Ferrs,
- Cristaux
- Antiferro
- CuZn
- BaTiO<sub>3</sub>

- Cristaux liquides

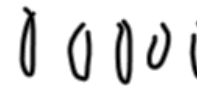

 Nématique



Smectic C

Smectic A





## Origine physique de l'ordre

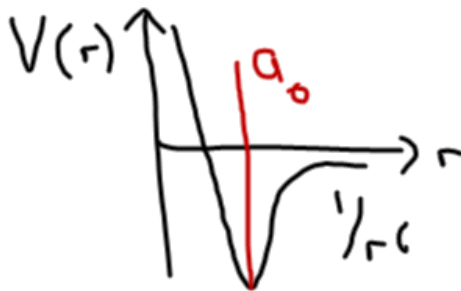
Ferroaimant

$$H = -J \sum_{\langle i,j \rangle} \vec{S}_i \cdot \vec{S}_j$$

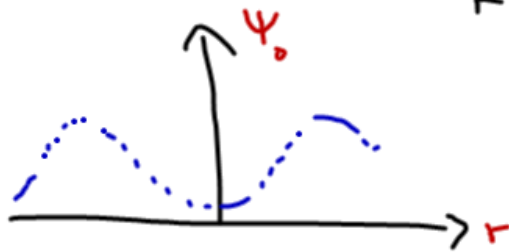
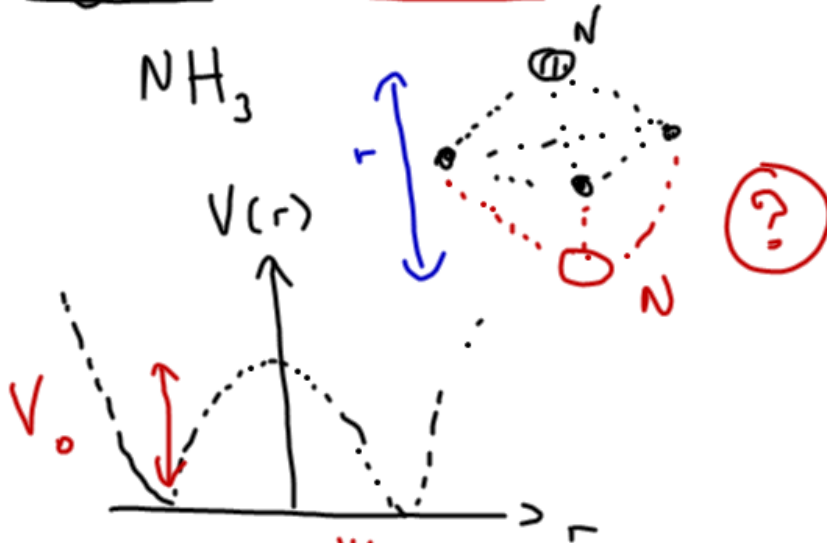
$$J > 0$$



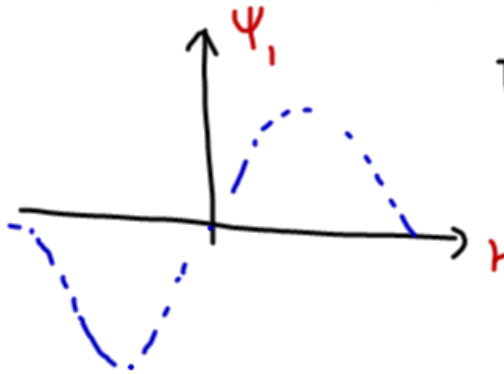
Solides (Ne, Ar)



# Symétrie brisée



$$|\phi\rangle = \frac{1}{\sqrt{2}} (|\psi_0\rangle + |\psi_0\rangle)$$

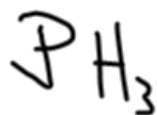


$$|\phi(t)\rangle = e^{-iHt/\hbar} |\phi\rangle$$

$$= \frac{1}{\sqrt{2}} (e^{-i\omega_0 t} |\psi_0\rangle + e^{i\omega_0 t} |\psi_1\rangle)$$

$$\Delta\omega = 24 \text{ GHz } (2\pi)$$

maser



## Autre façon de voir

Ferroaimant :

$$\lim_{r_i - r_j \rightarrow \infty} \langle S_i^z S_j^z \rangle = \text{cte}$$

$$\langle \Theta \rangle = \frac{\text{Tr} [e^{-\beta H} \Theta]}{\text{Tr} [e^{-\beta H}]}$$

$$= \frac{\sum_i \langle i | e^{-\beta E_i} \Theta | i \rangle}{\sum_i \langle i | e^{-\beta E_i} | i \rangle}$$

$$\lim_{r_i - r_j \rightarrow \infty} \langle S_i^z S_j^z \rangle = \langle S_i^z \rangle \langle S_j^z \rangle$$

Paramètre d'ordre

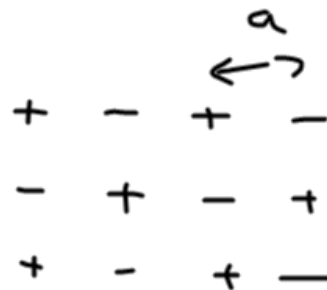
$\langle S_i^z \rangle$  à droite

$$\langle S_i^z \rangle = \lim_{h \rightarrow 0} \lim_{V \rightarrow \infty} \frac{\text{Tr} \left[ e^{-\beta(H - h S_i^z)} S_i^z \right]}{\text{Tr} \left[ e^{-\beta(H - h S_i^z)} \right]}$$

↑  
Champ externe

Exemples :

Antiferromagnet



$$\langle (-1)^i S_i^z (-1)^j S_j^z \rangle \xrightarrow{r_i - r_j \rightarrow \infty} \langle (-1)^i S_i^z \rangle \langle (-1)^j S_j^z \rangle$$

Paramètre d'ordre

$$(-1)^i = e^{i\vec{Q} \cdot \vec{r}_i}$$

$$\vec{Q} = \left( \frac{\pi}{a}, \frac{\pi}{a} \right)$$

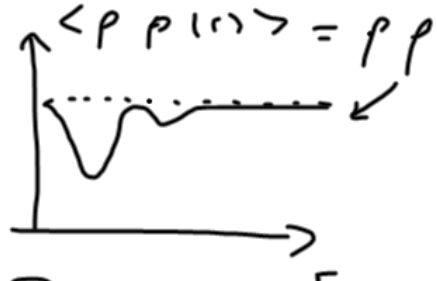
- CuZn

$$\lim_{r_i - r_j \rightarrow \infty} \langle \rho_{Cu}(i) \rho_{Cu}(j) \rangle$$

Selon le site.  $\left\{ \begin{array}{l} = \langle \rho_{Cu} \rangle \langle \rho_{Cu} \rangle \neq 0 \\ = 0 \end{array} \right.$



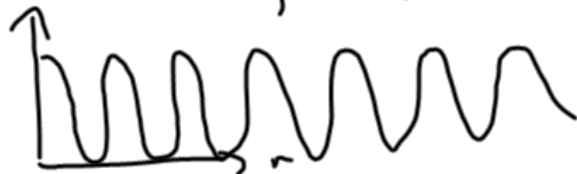
• Liquide ou gaz



• Ferroélectrique. BaTiO3

$$\langle P^2(r_i) P^2(r_j) \rangle \xrightarrow{r_i - r_j \rightarrow \infty} \langle P^2 \rangle^2$$

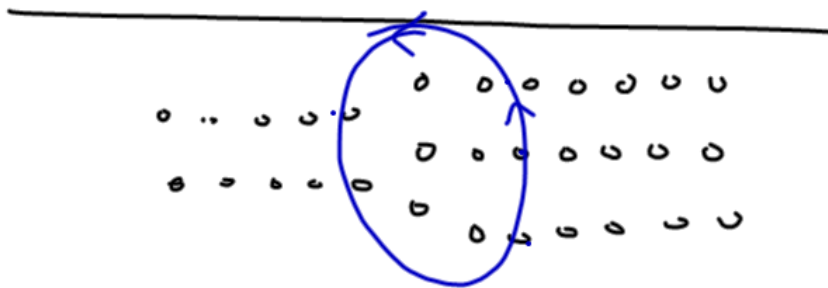
• Solide.



$$\frac{1}{V^2} \int d^3r d^3r' \langle \rho(r) e^{iG \cdot (r-r')} \rho(r') \rangle$$

$$= \langle \rho_G \rangle \langle \rho_G \rangle$$

$n \mathbf{Q}_i = \vec{G} \cdot \vec{R}$  où  $\vec{R}$  = vecteur du réseau de Bravais.



• Supraconducteur

$$\langle c_{\uparrow}^{\dagger} c_{\downarrow}^{\dagger} c_{\downarrow}(r) c_{\uparrow}(r) \rangle \xrightarrow{r \rightarrow \infty}$$

$$\langle c_{\uparrow}^{\dagger} c_{\downarrow}^{\dagger} \rangle \langle c_{\downarrow} c_{\uparrow} \rangle$$

Paramètre d'ordre

$$\frac{\text{Tr} \left[ e^{-\beta(H - \mu N)} c_{\uparrow}^{\dagger} c_{\downarrow}^{\dagger} \right]}{\text{Tr} \left[ e^{-\beta(H - \mu N)} \right]}$$

# Conséquence de la brisure de symétrie

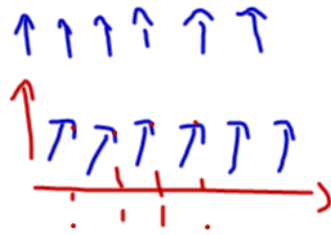
- Rigidité

- Excitations

- Défauts

→ Symétrie qui est brisée est continue!

e.g. ferroaimant.



Le "mode" qui restaure la symétrie coûte

0 énergie. Il fait partie d'une "branche d'excitations"

