Couplage magnéto-électrique dans les matériaux multiferroïques

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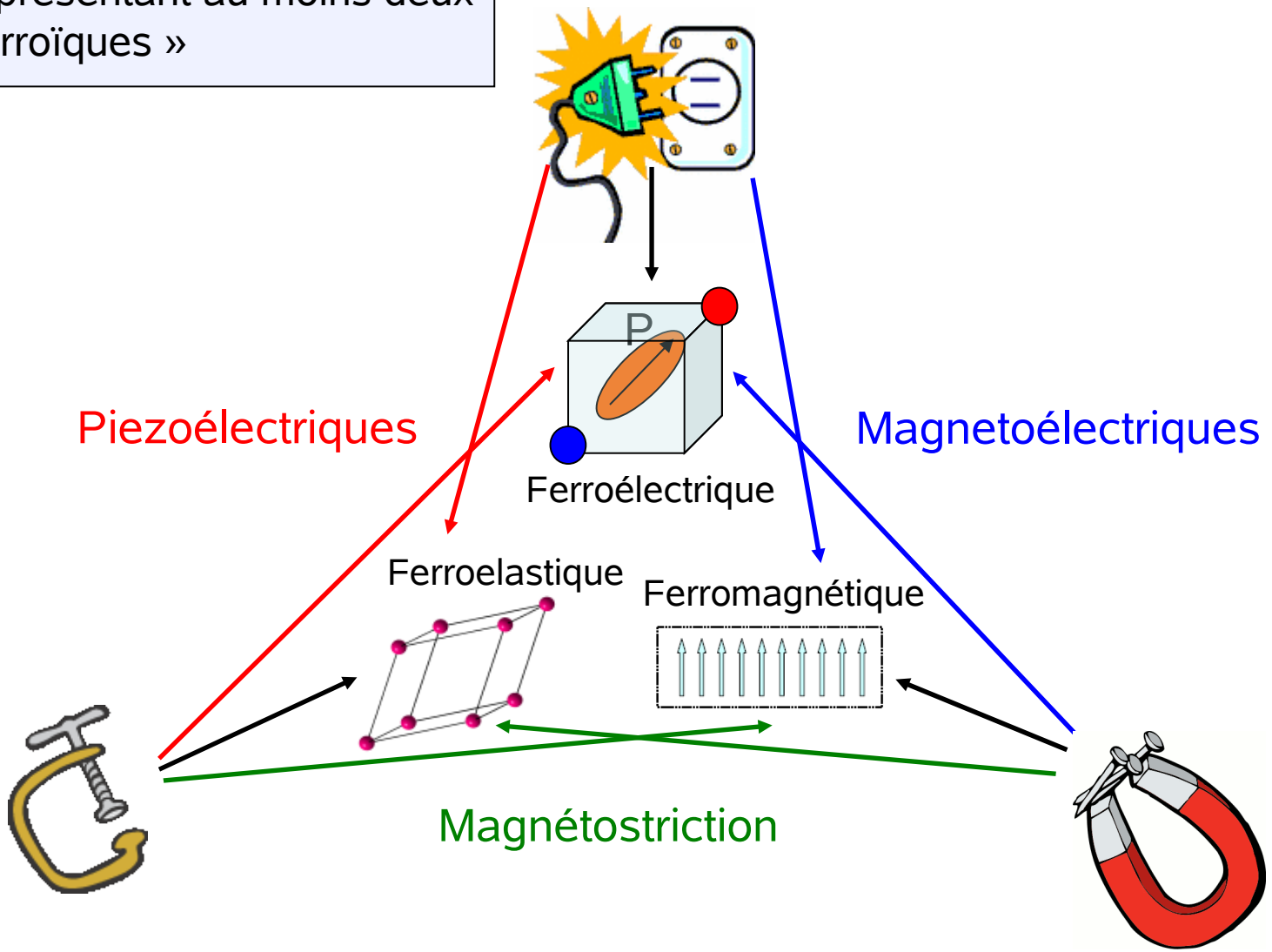
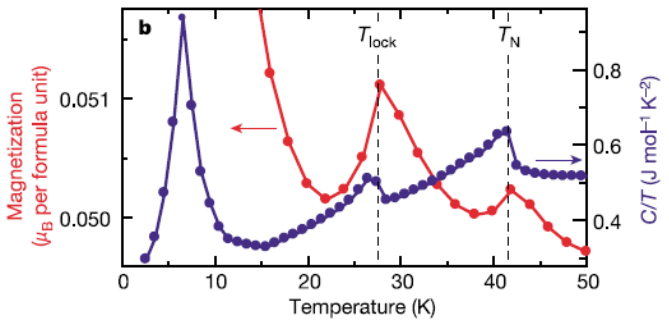
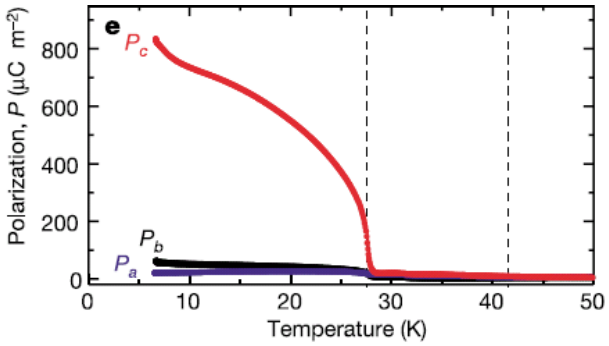
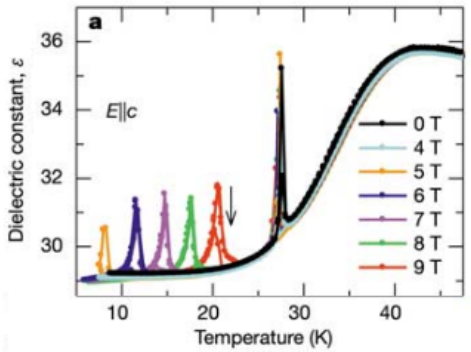
Matériaux présentant au moins deux ordres « ferroïques »



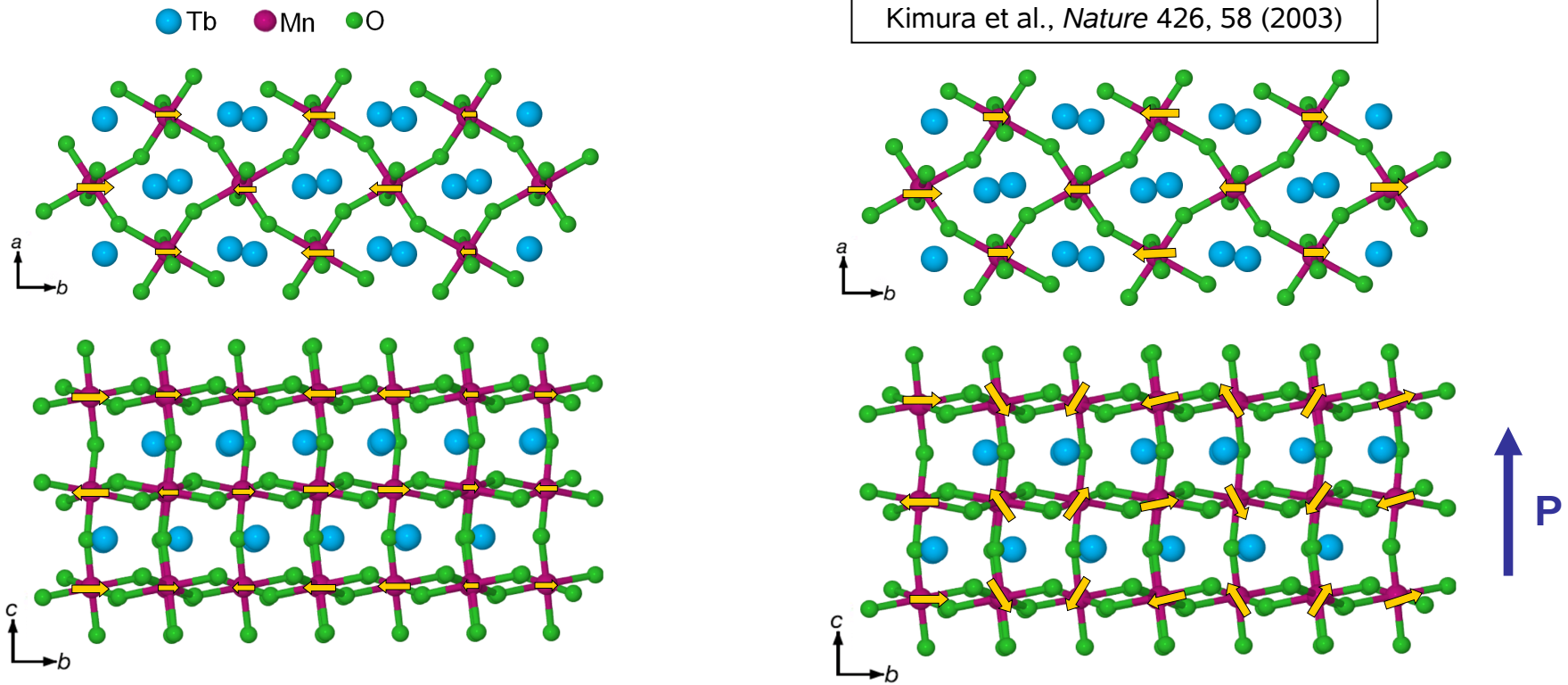
$TbMnO_3$: Structure et transitions de phase







Kimura et al., *Nature* 426, 58 (2003)



$T_C < T < T_N$

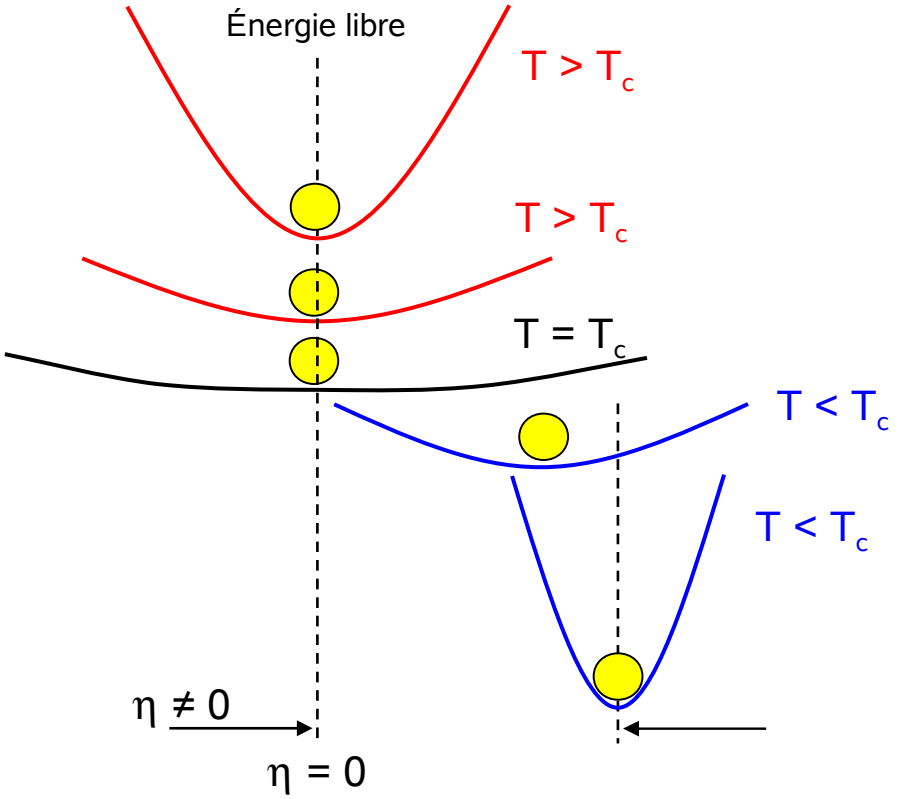
$T_N = 41$ K $T_C = 27$ K

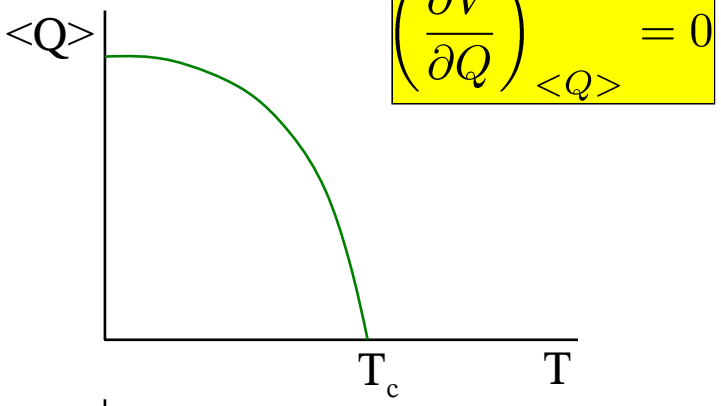
$T < T_C$

Ferroélectricité et mode mou

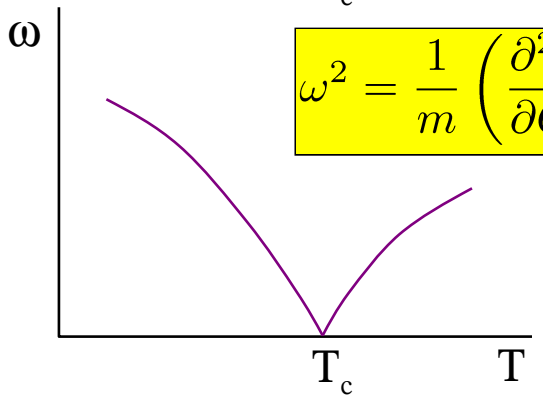
Q est une variable dynamique du système

Parmètre d'ordre $\eta = \langle Q \rangle$ $\begin{cases} = 0, & T > T_c \\ \neq 0, & T < T_c \end{cases}$





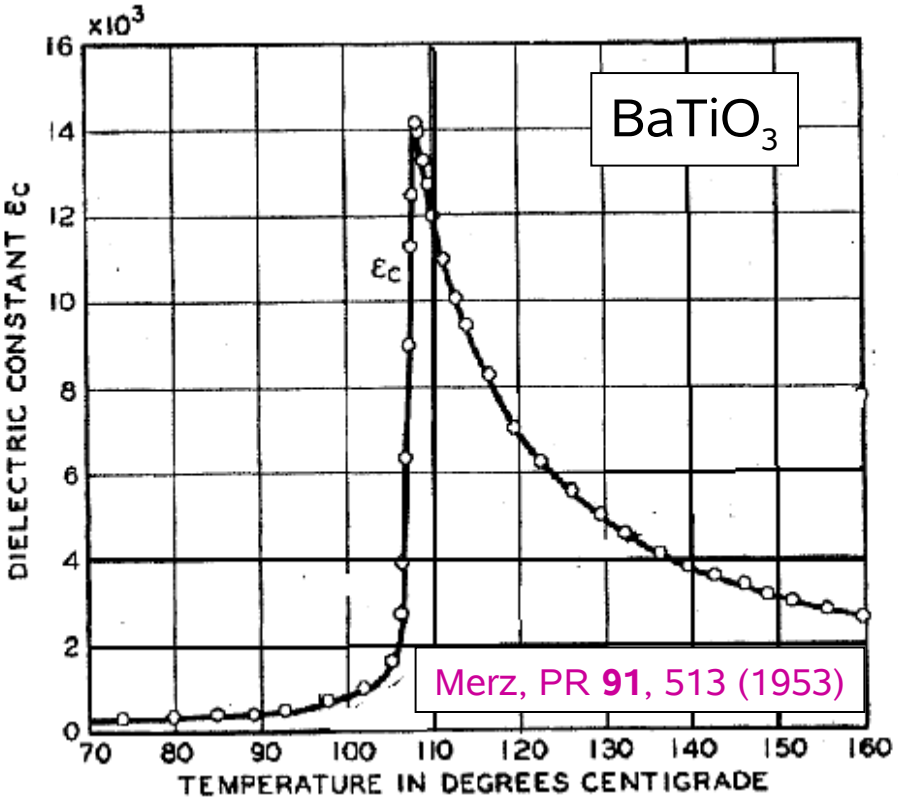
$$\left(\frac{\partial V}{\partial Q}\right)_{<Q>} = 0$$



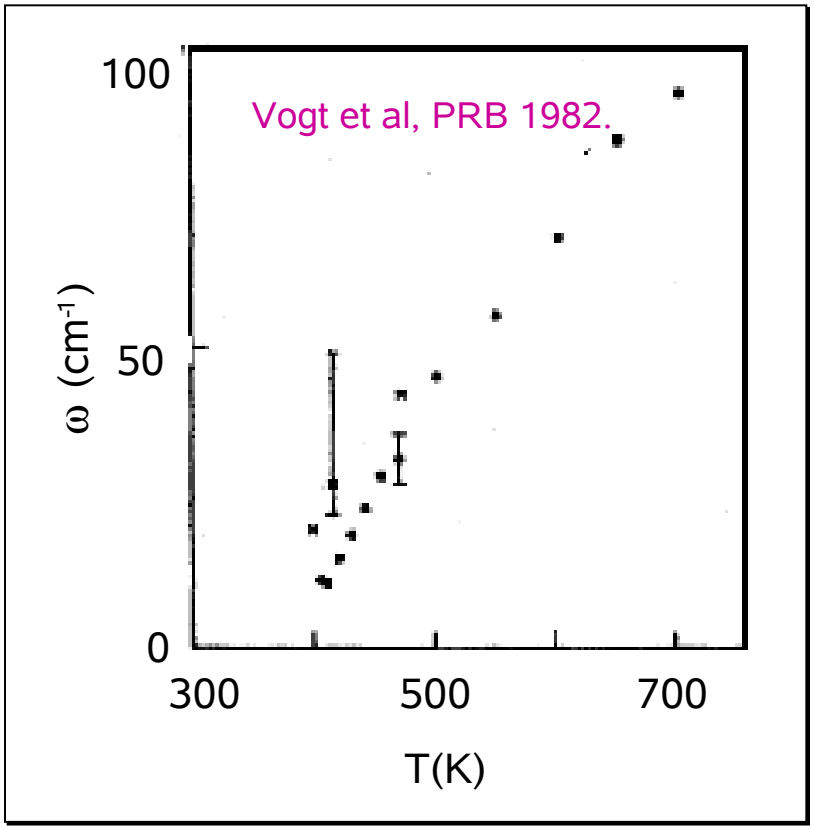
$$\omega^2 = \frac{1}{m}\left(\frac{\partial^2 V}{\partial Q^2}\right)_{<Q>}$$

Ferroélectricité et mode mou

Pour un phonon isolé : $$\frac{2}{\pi}\int \sigma_1(\omega)d\omega = \Delta\varepsilon_j\Omega_{0j}^2 \propto \frac{n_j q_j^2}{m_j} = const$$

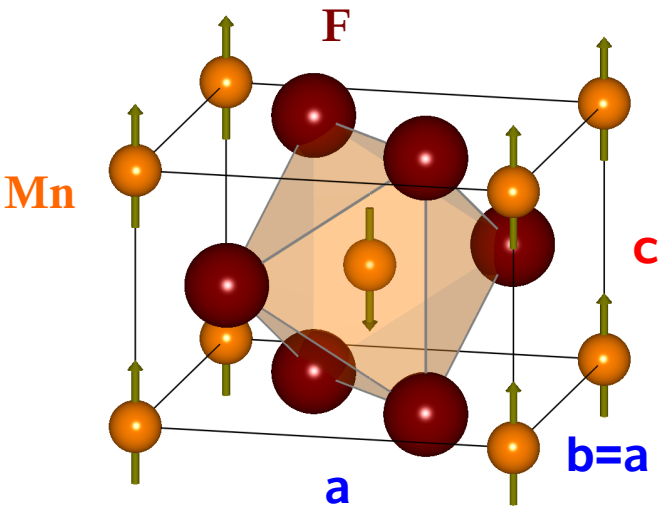


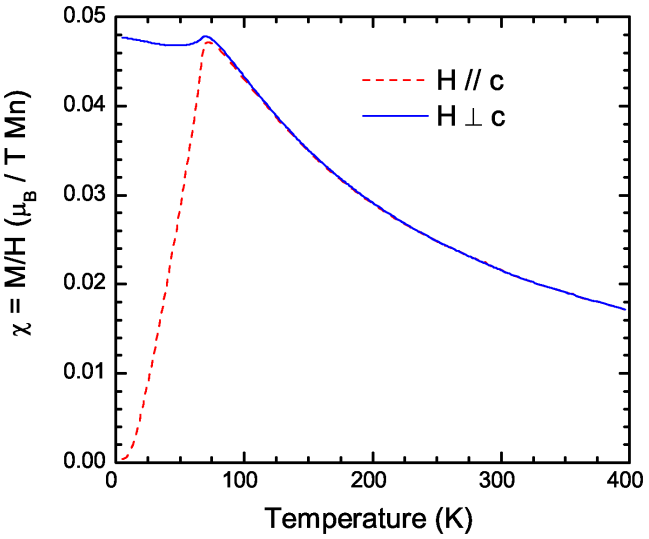
Merz, PR **91**, 513 (1953)



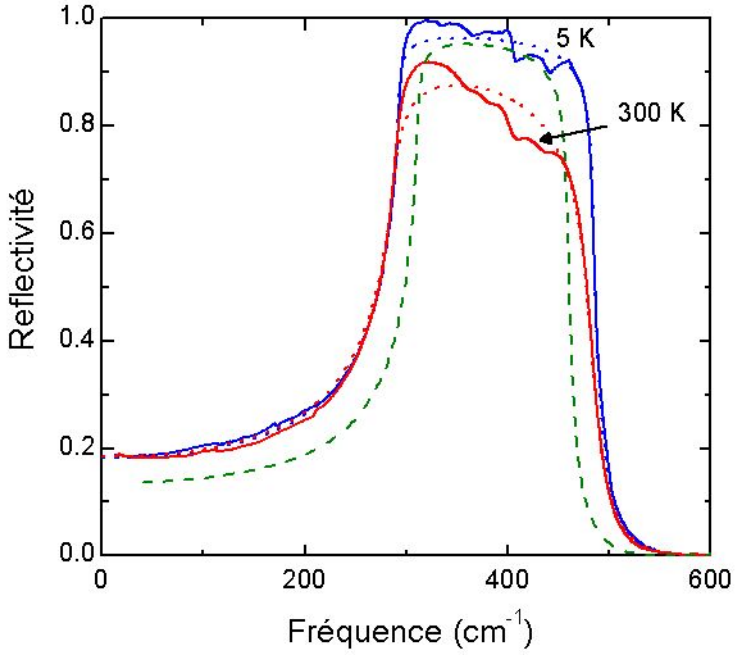
Vogt et al, PRB 1982.

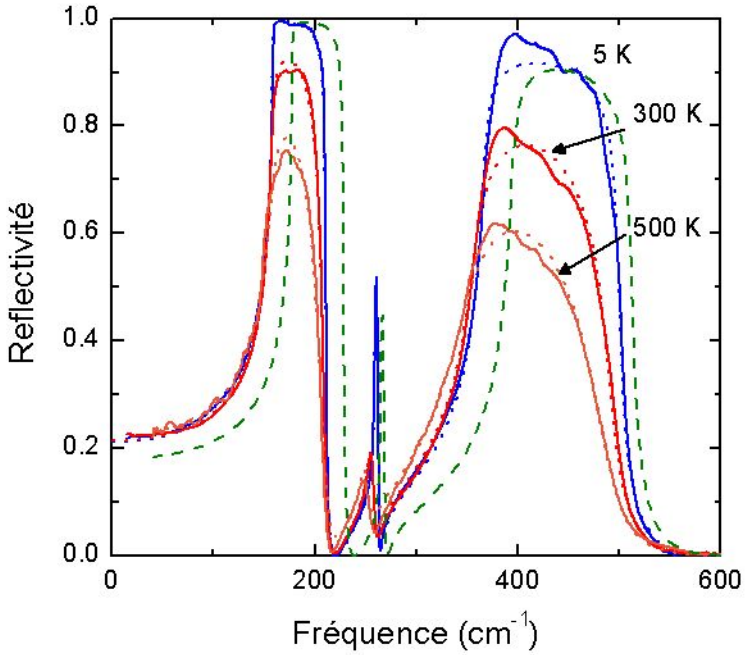
Plus simple : MnF_2, simplement antiferromagnétique



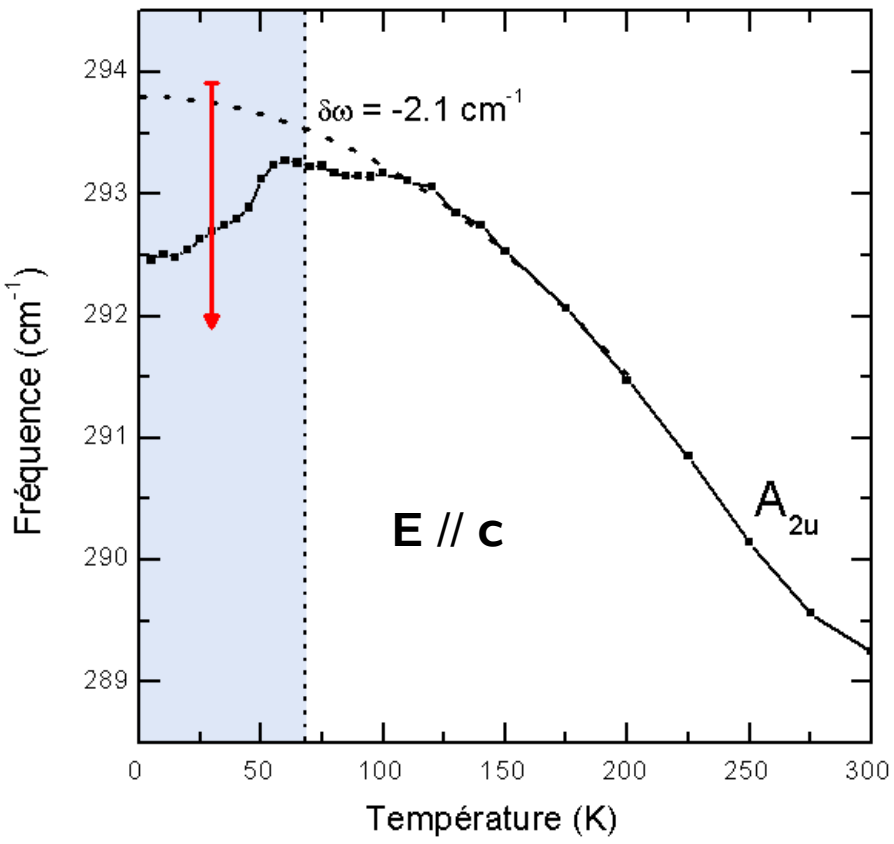


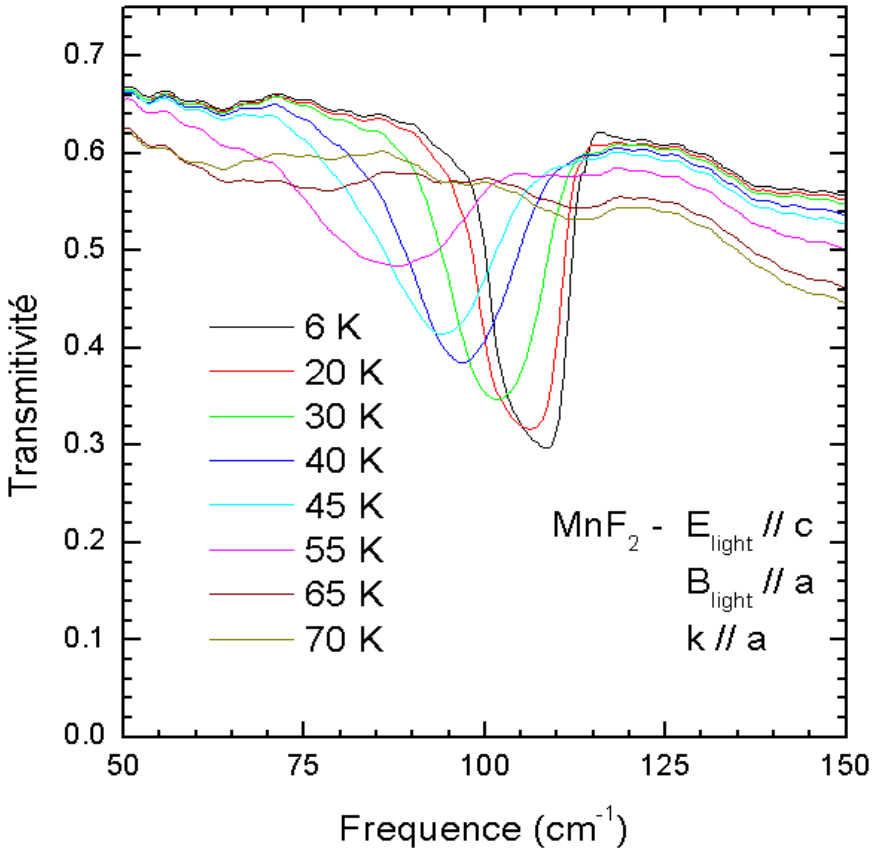
T_N = 67 K





MnF_2 : réponse infrarouge de l'axe c





MnF_2 : couplage magnéto-électrique : règle de somme

- Règle de somme optique (conservation du nombre de charges)

$$\int_0^\infty Re[\sigma(\omega)]\, d\omega = const \times \frac{n_e}{m_e}$$

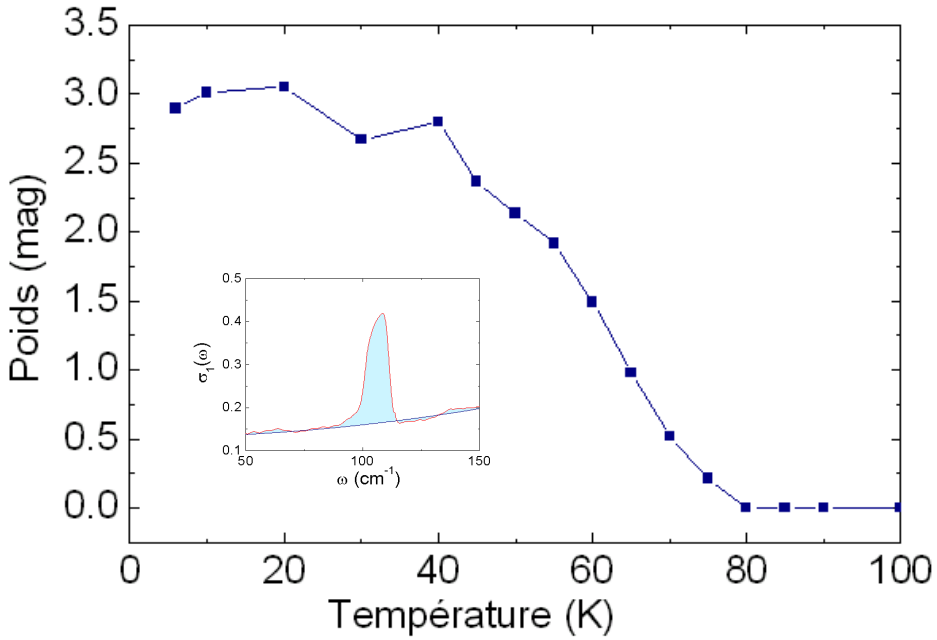
- Pour une excitation couplée à aucune autre :

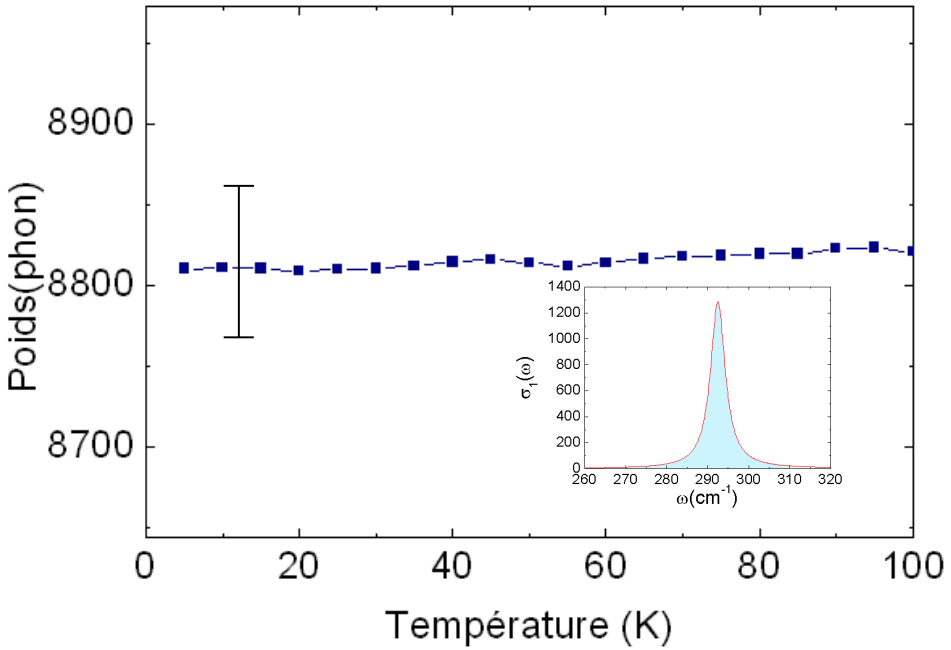
$$\int_{Excitation} \sigma_1(\omega)\, d\omega = const$$

- Si le système {magnons, phonons} est indépendant :

$$\underbrace{\int_{Magnons} \sigma_1(\omega)\, d\omega}_{\text{Poids spectral des magnons}} + \underbrace{\int_{Phonons} \sigma_1(\omega)\, d\omega}_{\text{Poids spectral des phonons}} = const$$

MnF_2 : couplage magnéto-électrique : règle de somme





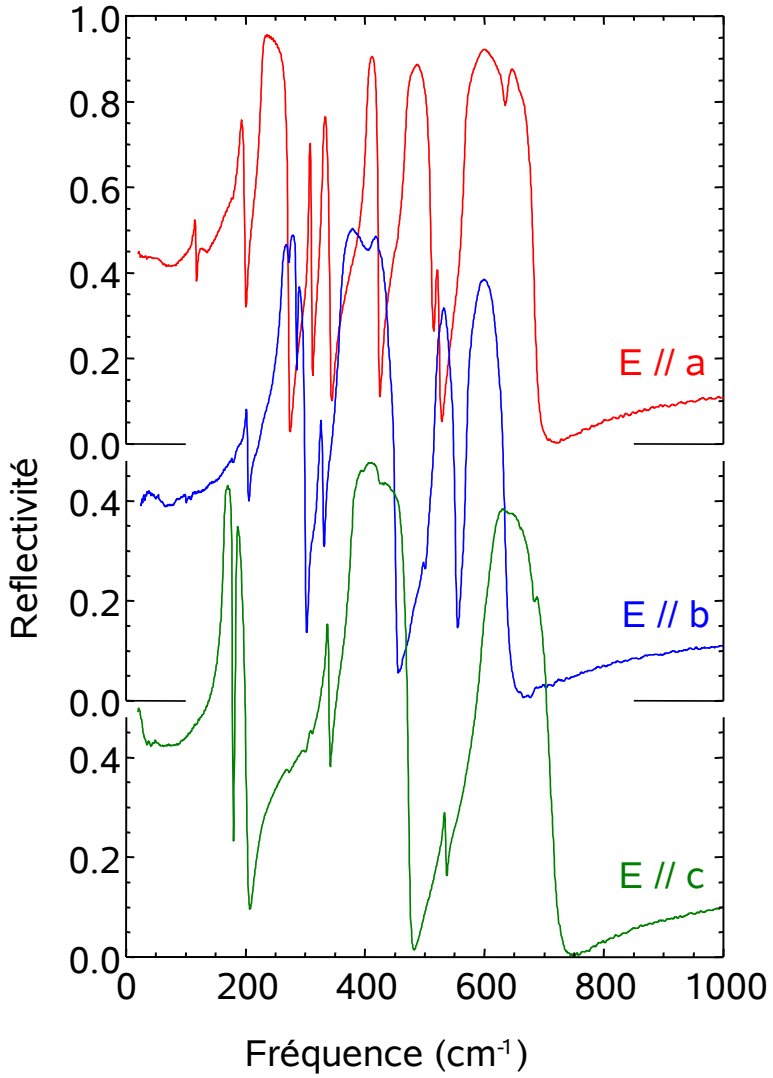
$$Poids(mag) = \int_{2-Magnon} \sigma_1(\omega)\, d\omega \approx 2.8$$

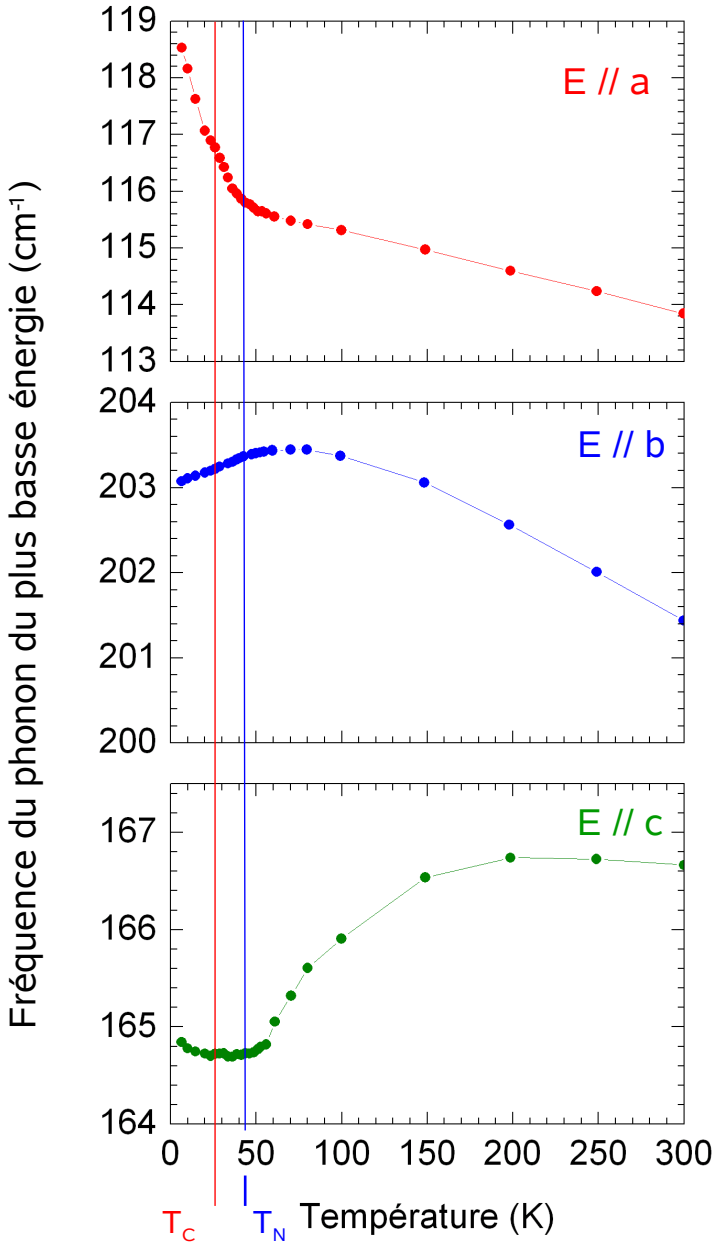
$$Poids(phon) = \int_{Phonon} \sigma_1(\omega)\, d\omega \approx 8400$$

$$\frac{Poids(mag)}{Poids(phon)} \approx 3\ 10^{-4}$$

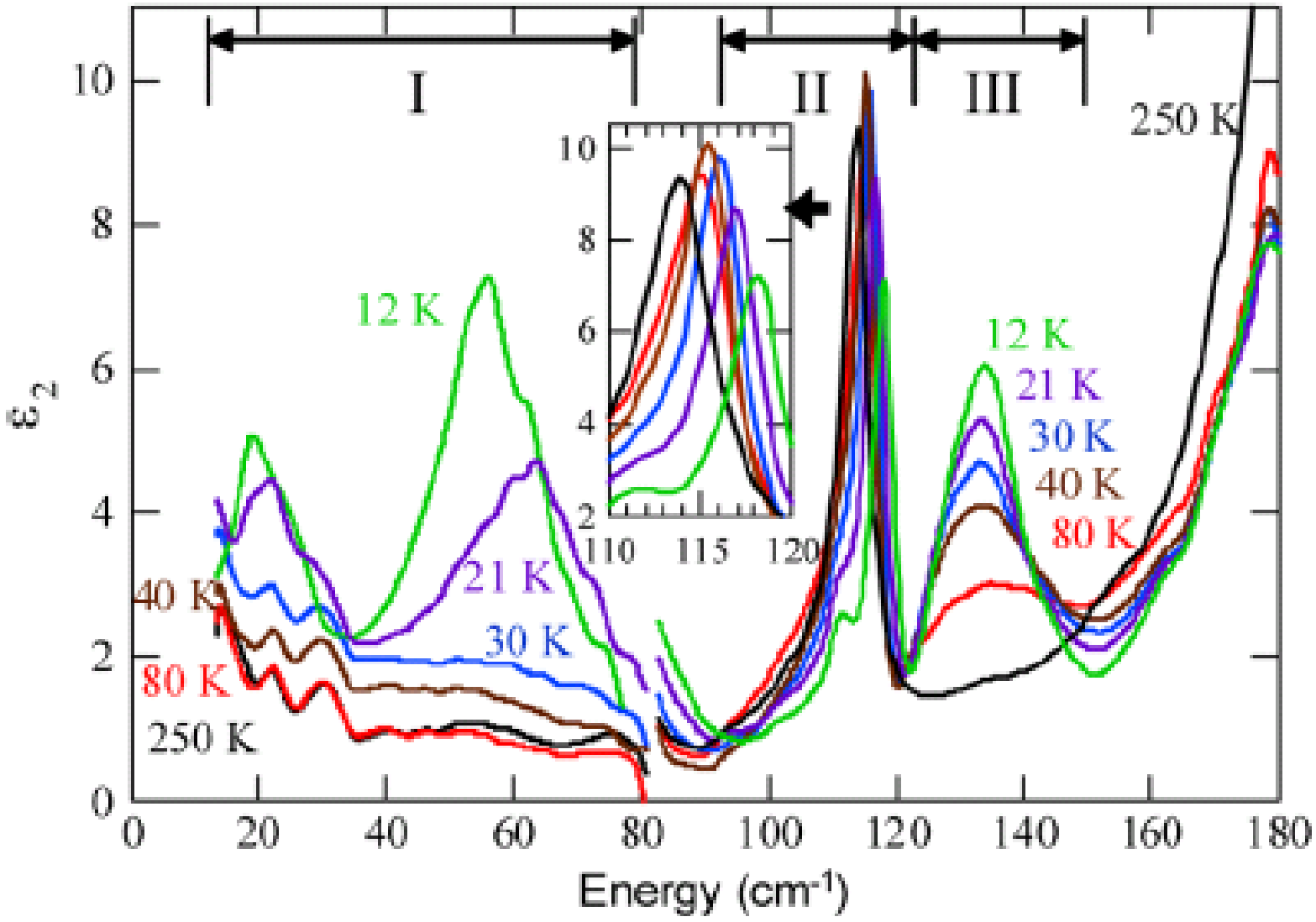
On ne peut pas voir un changement relatif de 3 10^{-4} dans le poids spectral du phonon ! Donc on ne peut pas conclure sur un éventuel transfert de poids spectral.

$TbMnO_3$: Reflectivité



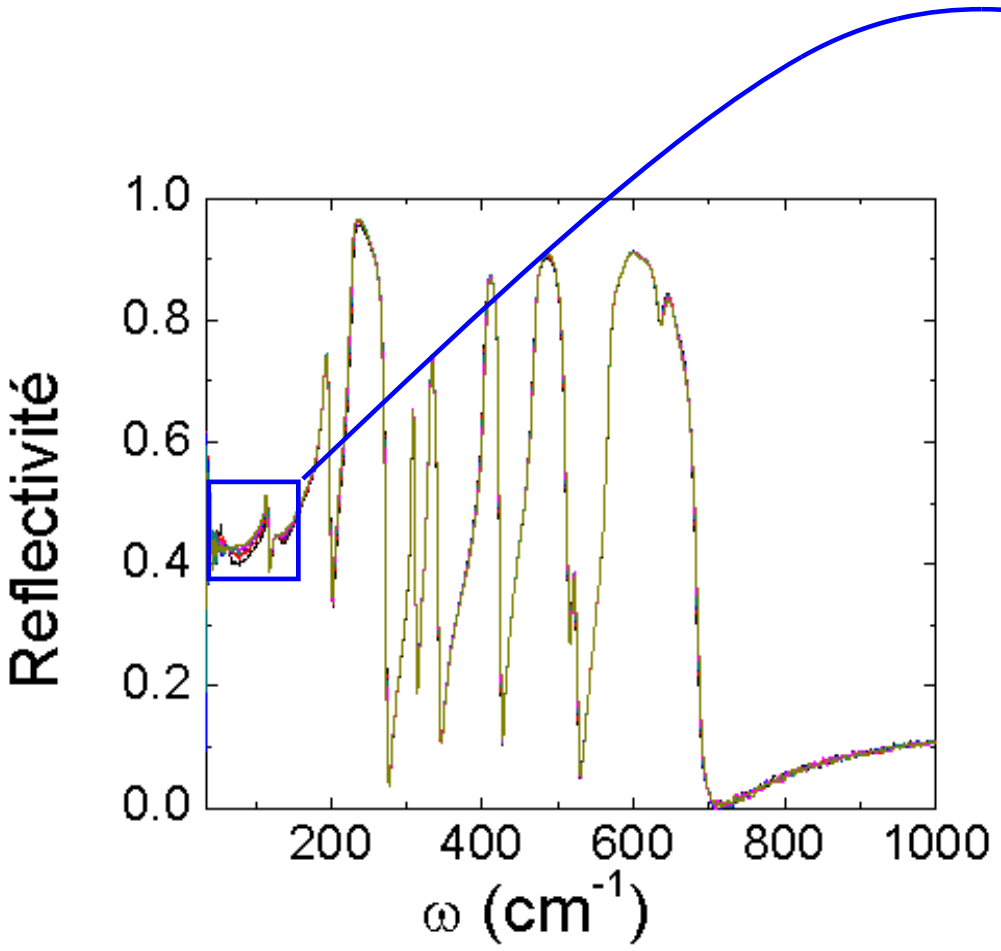


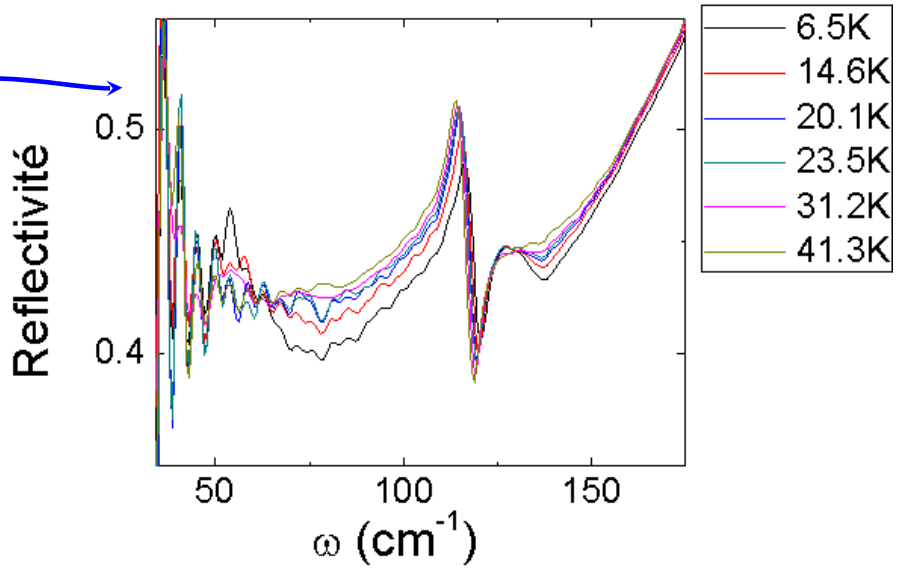
$TbMnO_3$: l'axe a

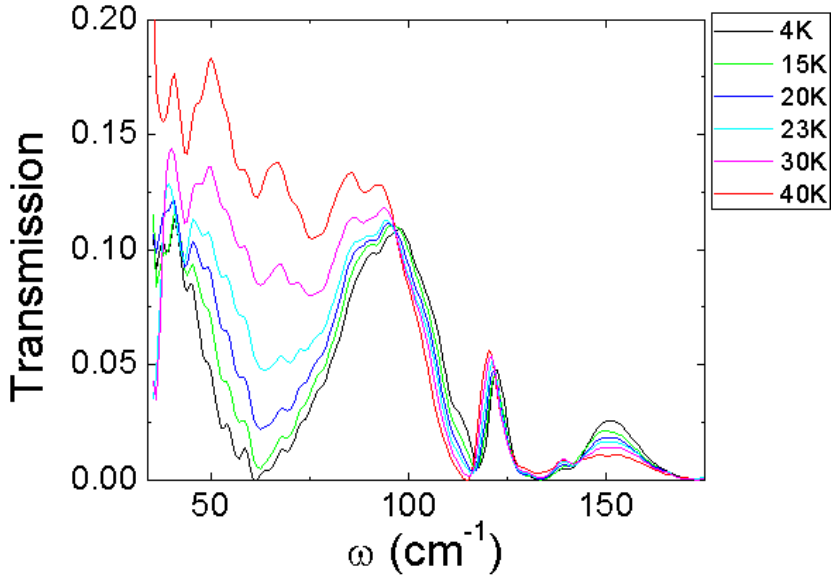


Takahashi et al., PRL 101, 187201 (2008)

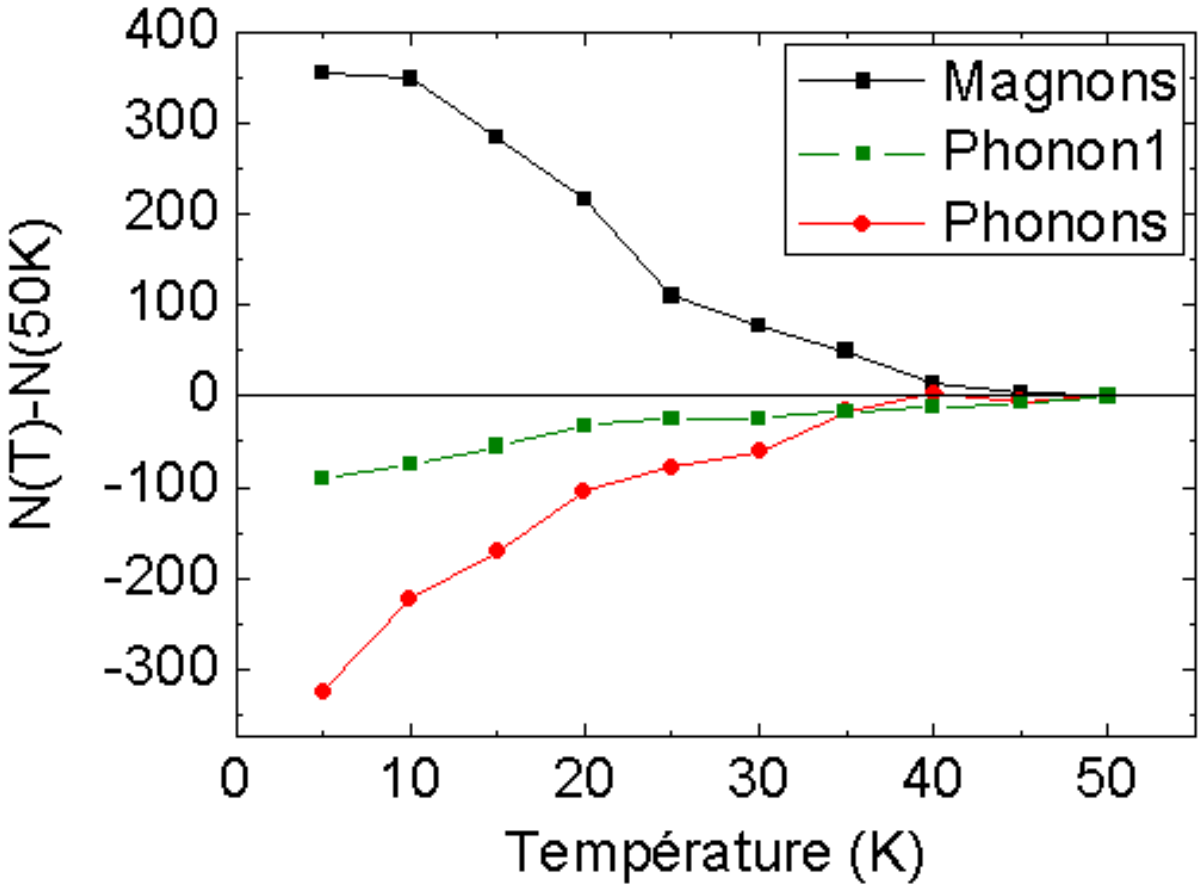
$TbMnO_3$: l'axe a





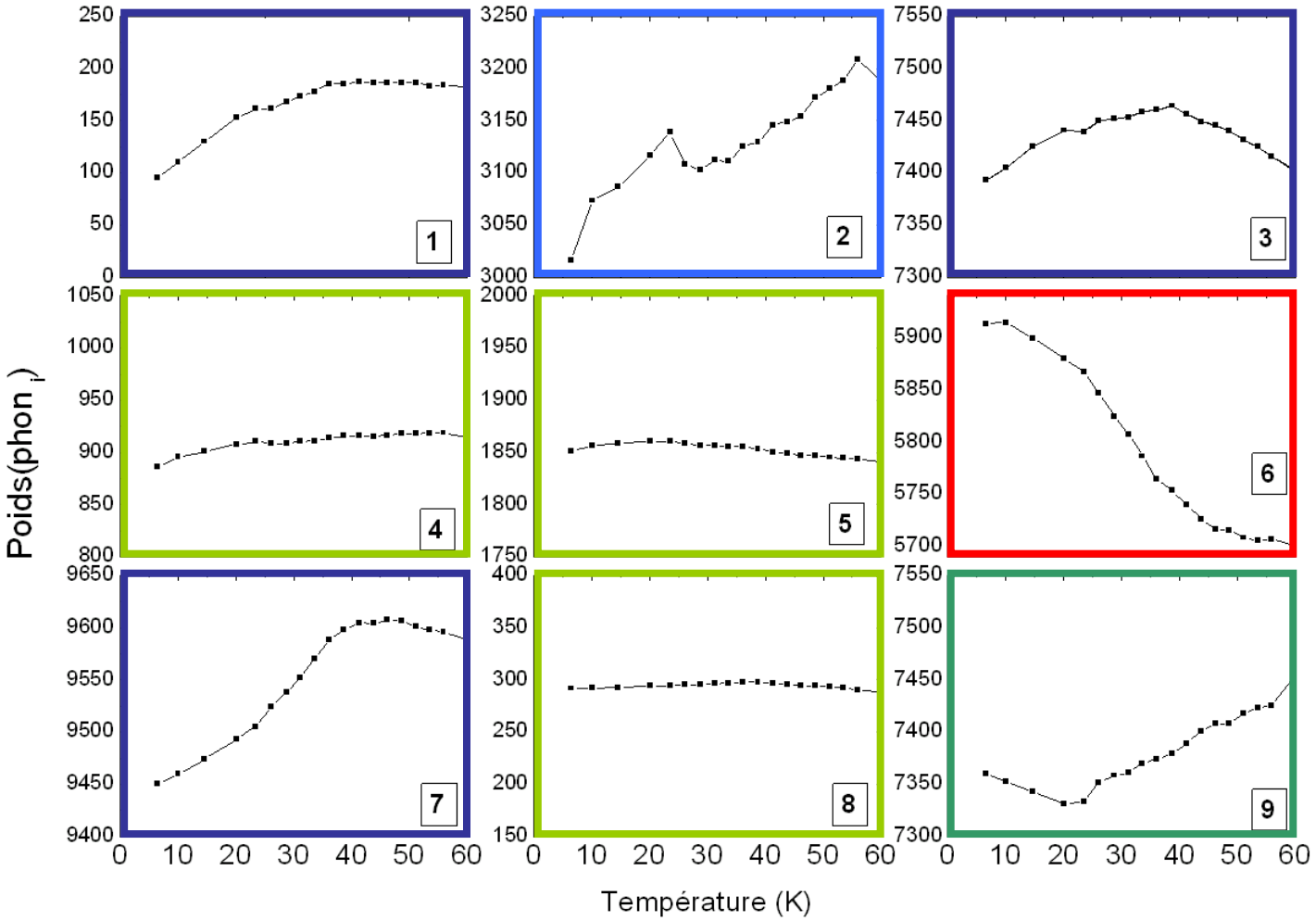


$TbMnO_3$: transfert de poids spectral



Il y a un transfert de poids spectral des magnons vers **tous** les phonons quand la température augmente .

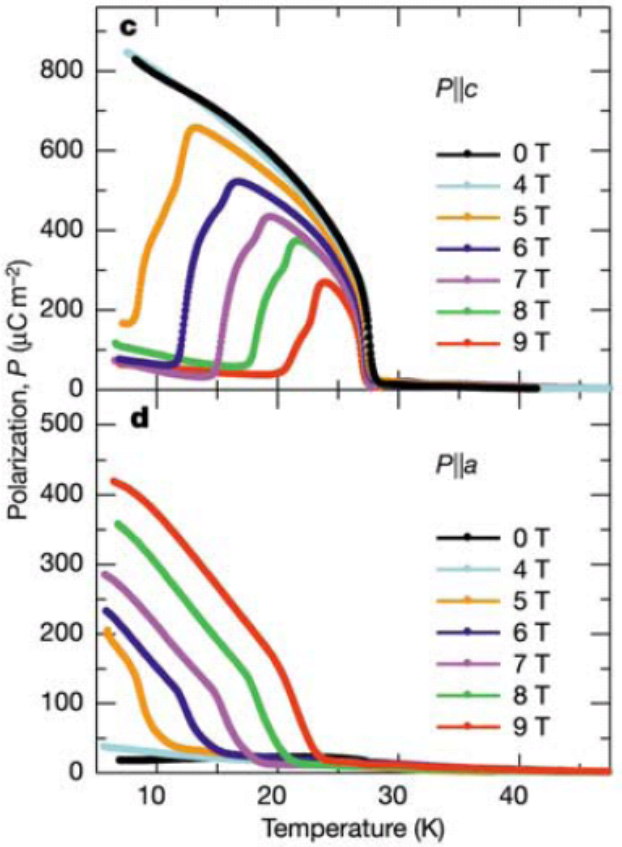
$TbMnO_3$: transfert de poids spectral… vers quels phonons ?



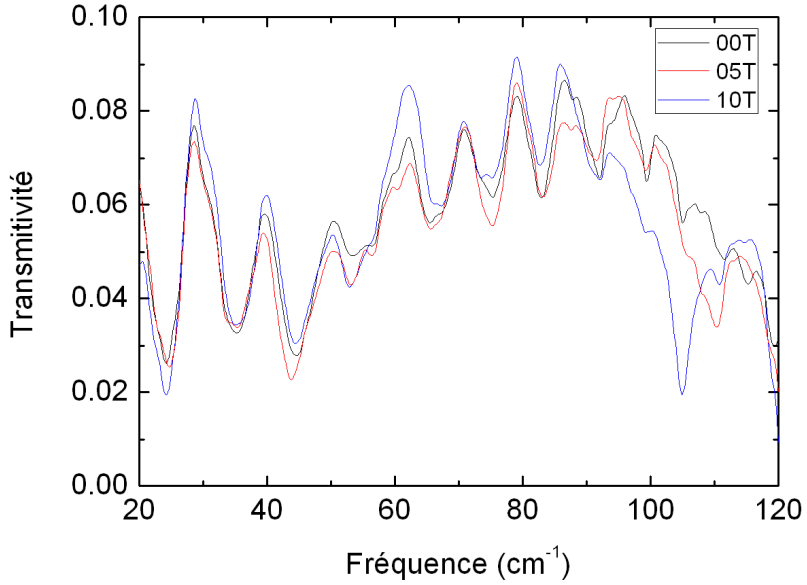
A priori, les phonons 1,2,3,6,7 et 9 sont couplés aux magnons.

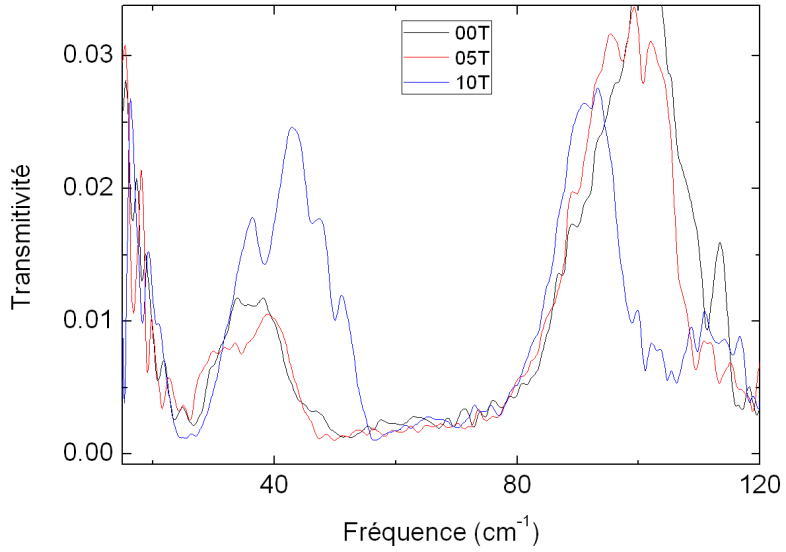
Mais 6 et 7 forment probablement un système isolé.

$TbMnO_3$: et avec un champ magnétique ?

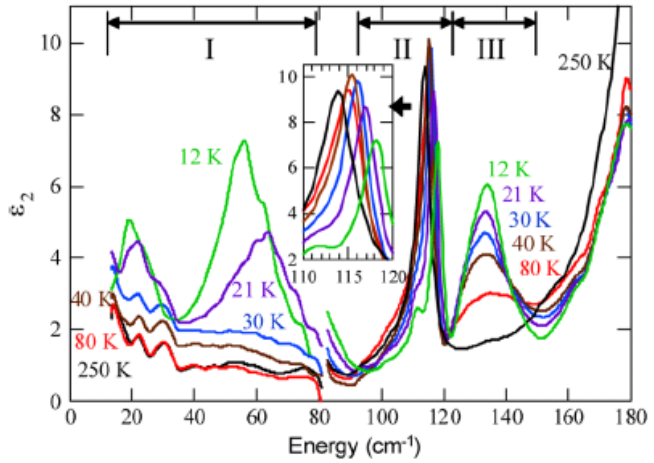


Kimura et al., *Nature* 426, 58 (2003)

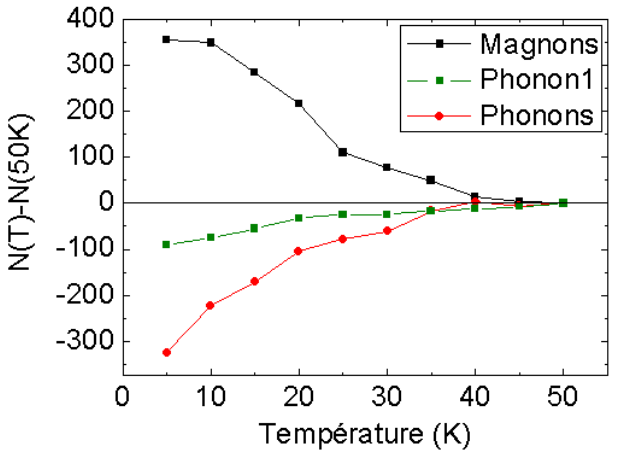




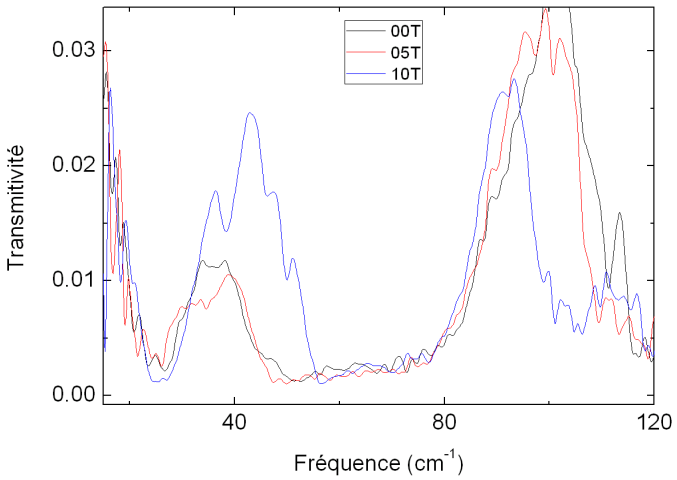
Conclusion



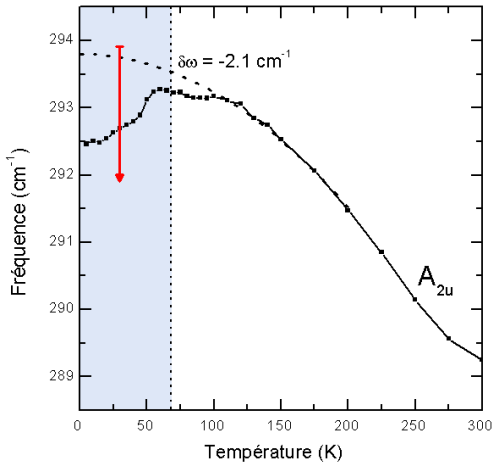
- Dans $TbMnO_3$ il y a un transfert de poids spectral entre les excitations magnétiques et les phonons



- Le transfert s'effectue vers **l'ensemble** des phonons.

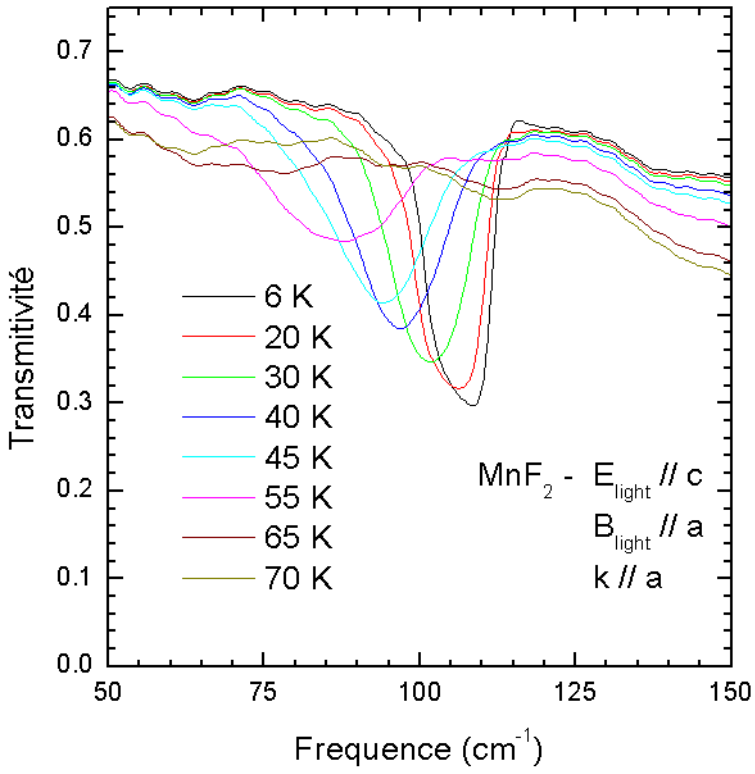


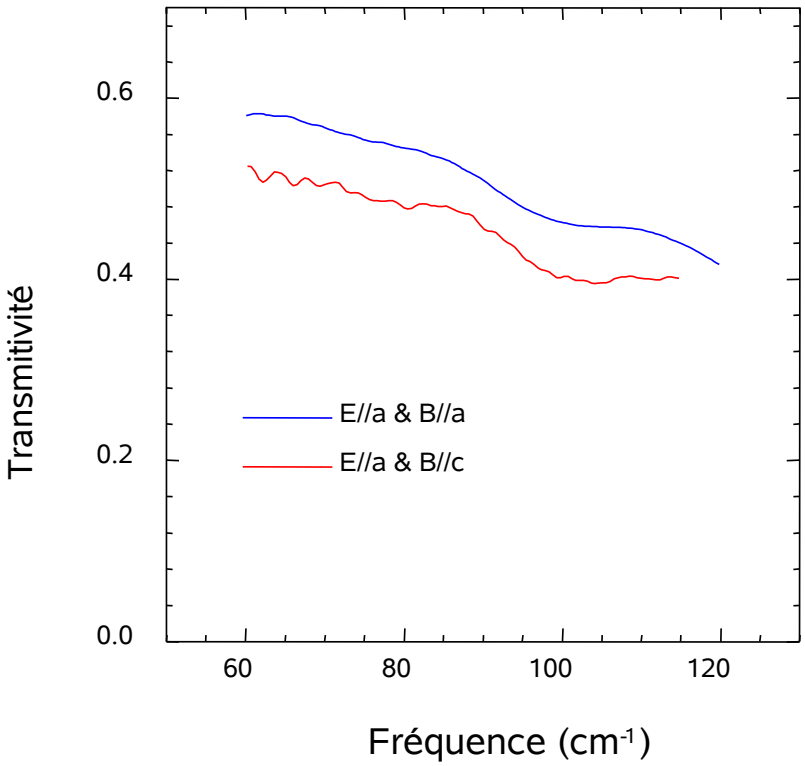
- L'application d'un champ magnétique selon **b** détruit une partie de l'excitation magnétique suivant **a**

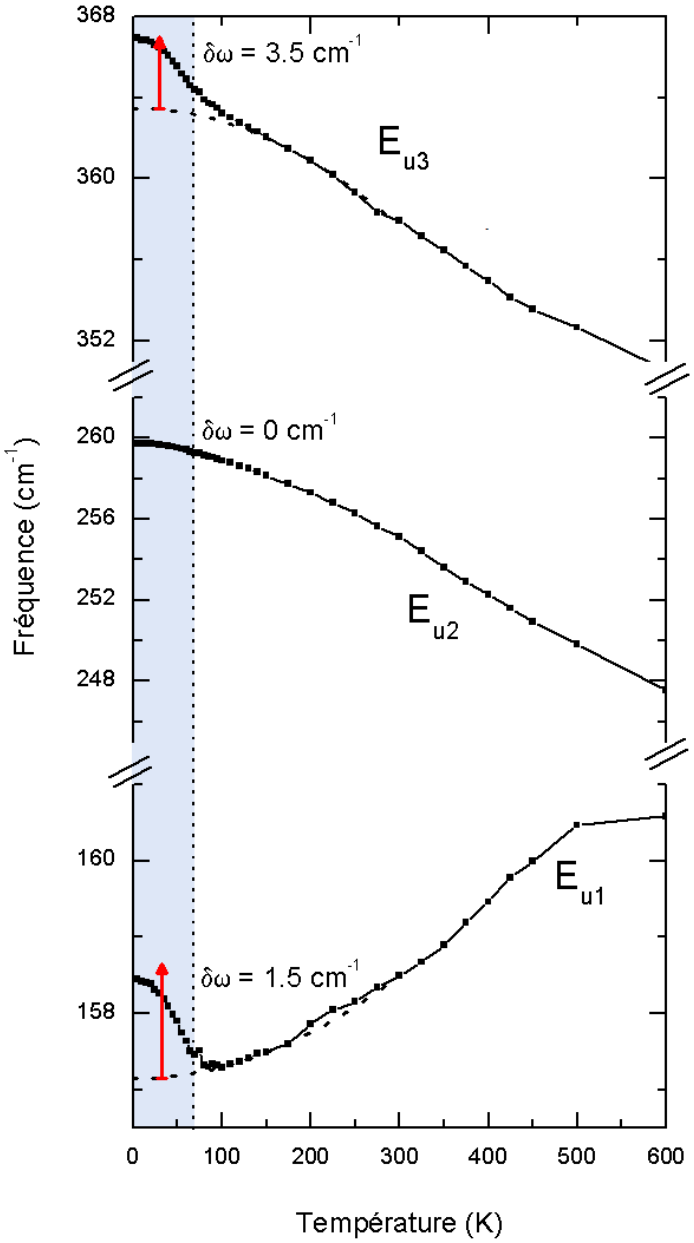


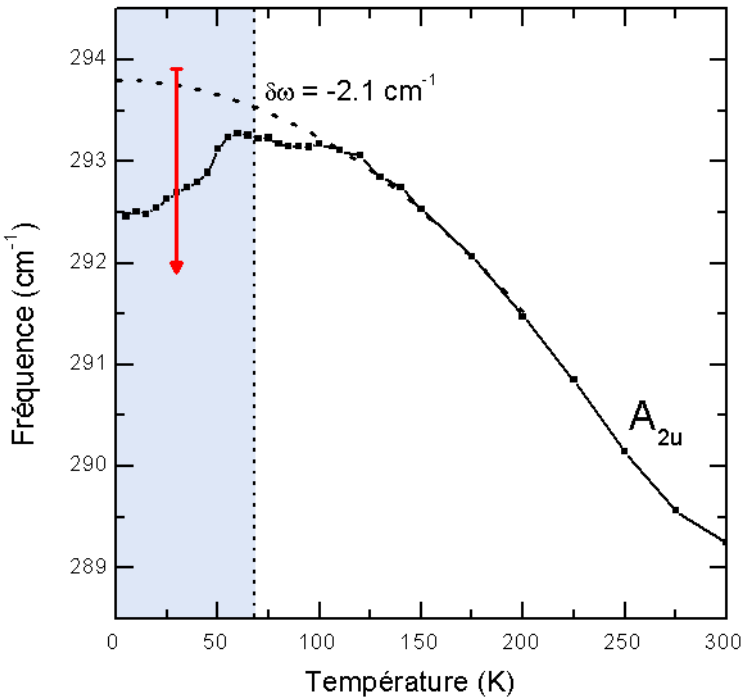
- Même les systèmes antiferromagnétiques les plus simples présentent un couplage magnéto-électrique (cf MnF_2)

FIN

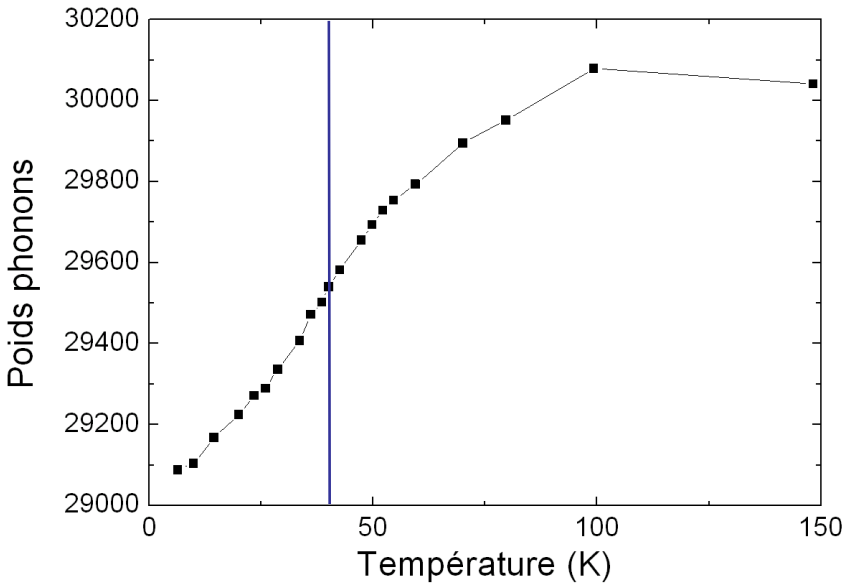

Transmitivité
Frequence (cm-1)
6 K
20 K
30 K
40 K
45 K
55 K
65 K
70 K
MnF2 - Elight // c
Blight // a
k // a

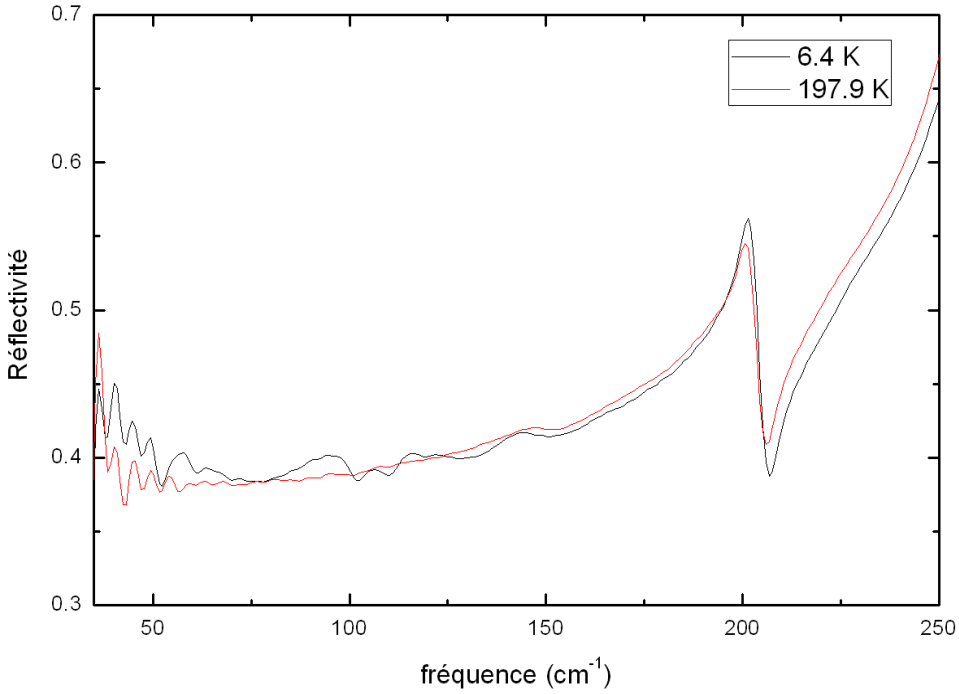

Transmitivité
Fréquence (cm-1)
E//a & B//a
E//a & B//c


368
360
352
δω = 3.5 cm-1
Eu3
260
256
252
248
δω = 0 cm-1
Eu2
160
158
Eu1
δω = 1.5 cm-1
Fréquence (cm-1)
0
100
200
300
400
500
600
Température (K)


294
293
292
291
290
289
δω = -2.1 cm-1
A2u
Fréquence (cm-1)
0
50
100
150
200
250
300
Température (K)

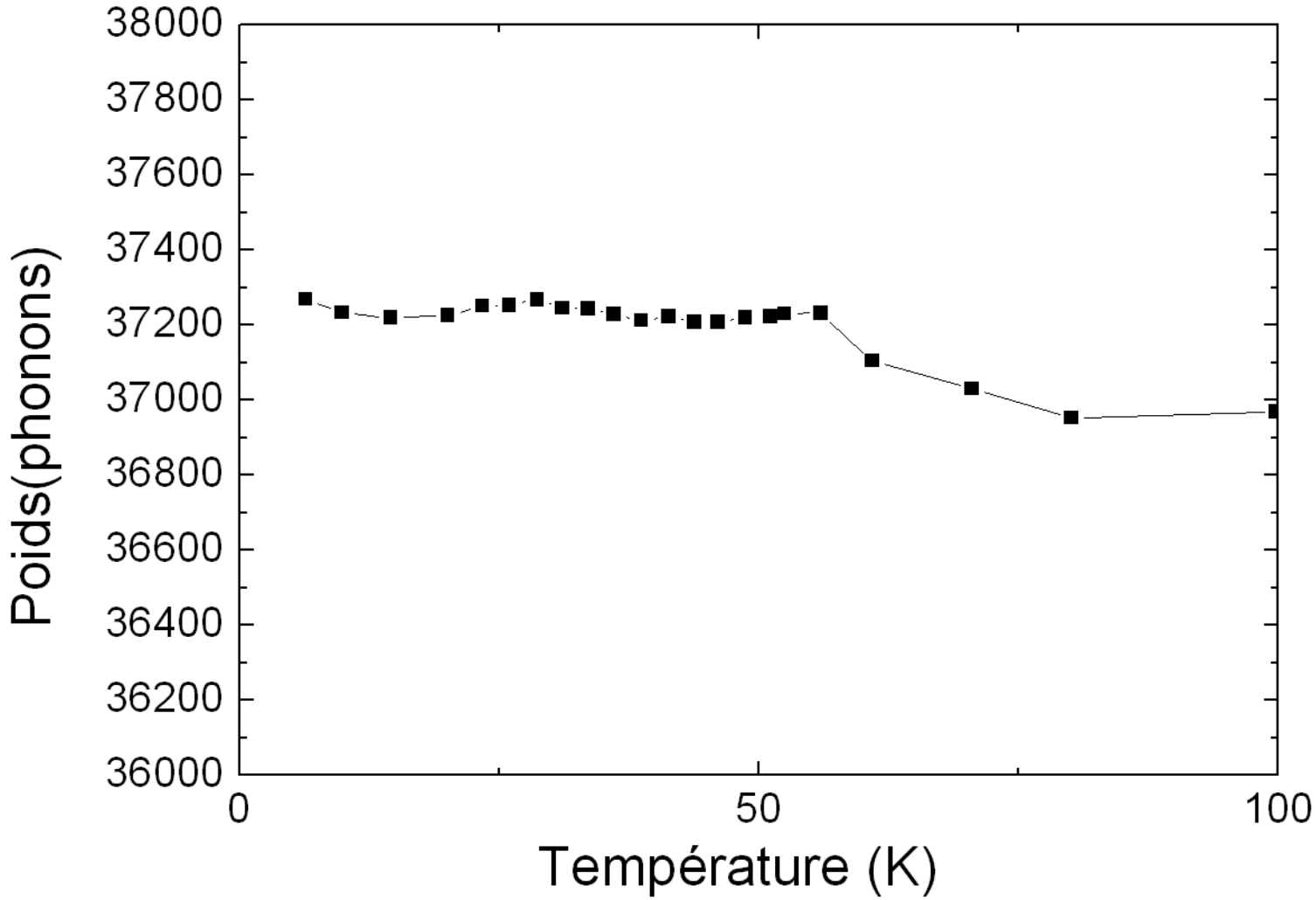
TbMnO3 : l'axe b

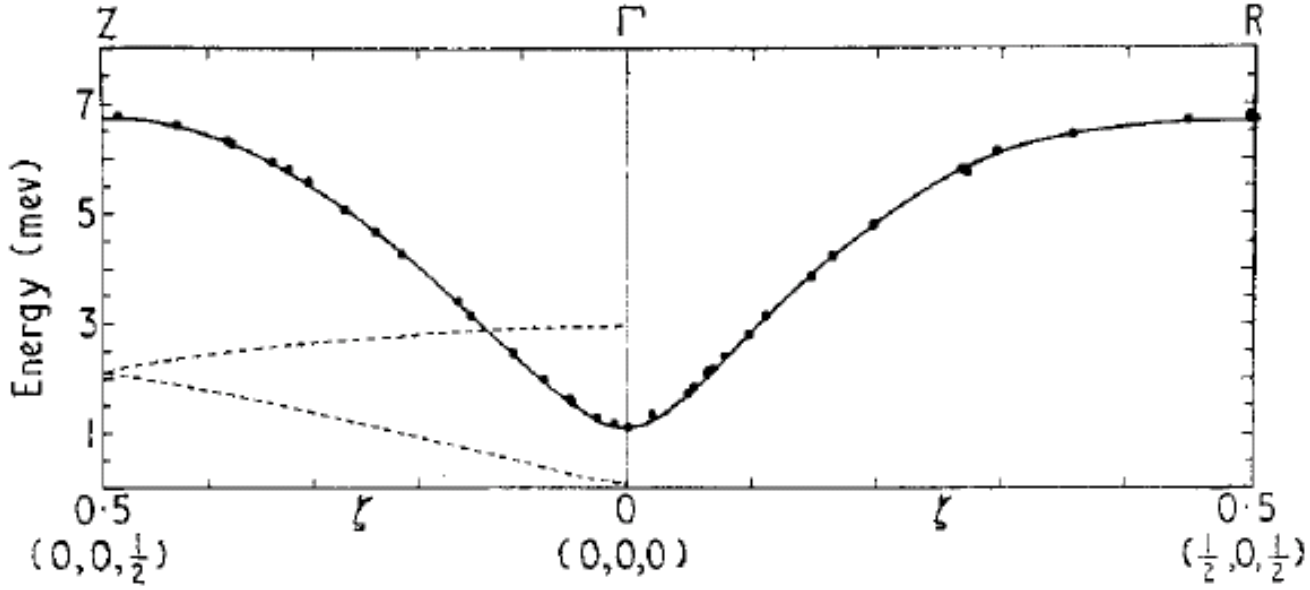




On note une diminution du poids spectral des phonons à basse température, mais pas d'accident à T_N.

TbMnO3 : l'axe c





1 mev = 8 cm^{-1}

NIKOTIN et al. *J. PHYS. C. (SOLID ST. PHYS.)*, 1969