Frustrácia v magnetickom analógu zamrznutej vody

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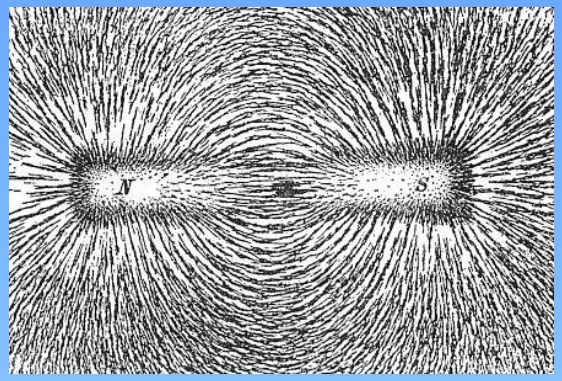
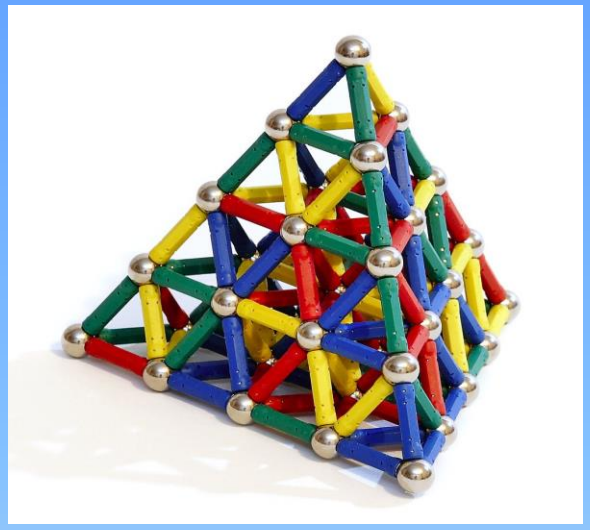
čínska „nebeská platňa“
dynastia Han (200 p. n. l)

Quid ferri duritia pugnacius ? Trahitur namque magnete lapide ... Plinius, Naturalis Historia (78)

Kalsem 2013, Třeboň, 28. 5. 2013

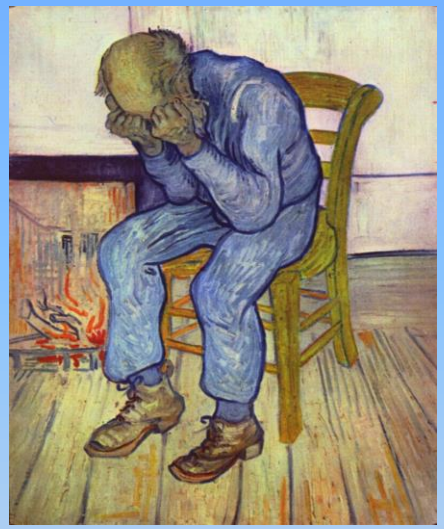




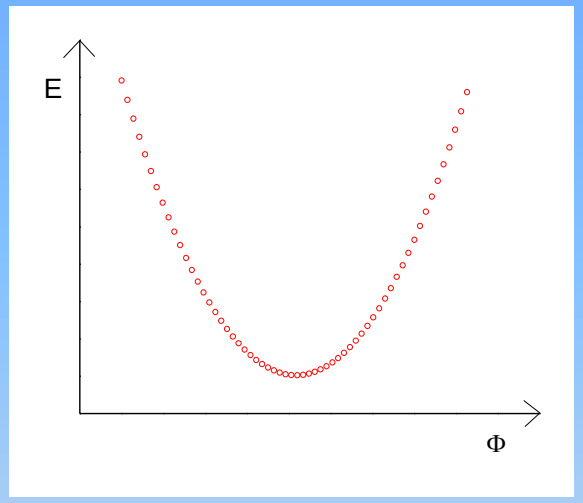
1. Geometricky frustrované systémy
2. Analógia medzi vodným a spinovým ľadom
3. Diracove monopóly v spinovom ľade
4. Termodynamické a relaxačné vlastnosti spinového ľadu
5. Zhrnutie

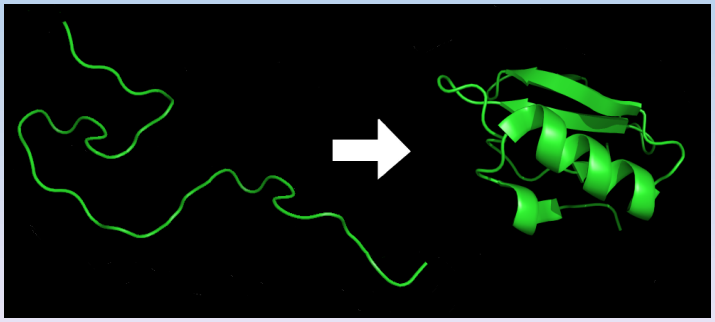
Geometricky frustrované systémy

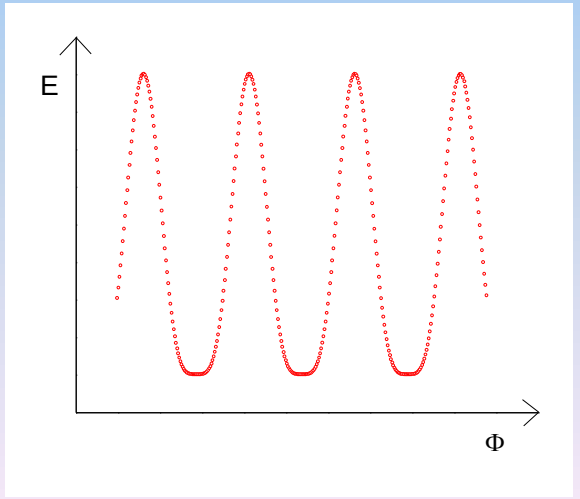
Frustrácia v živej prírode



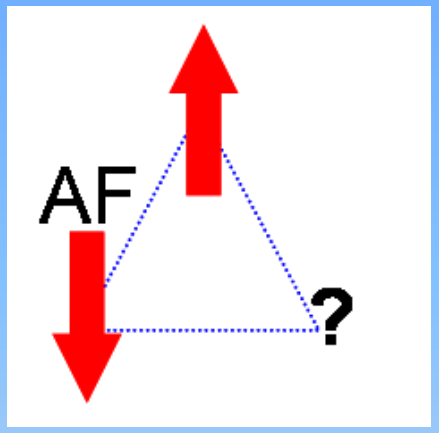
v neživej prírode

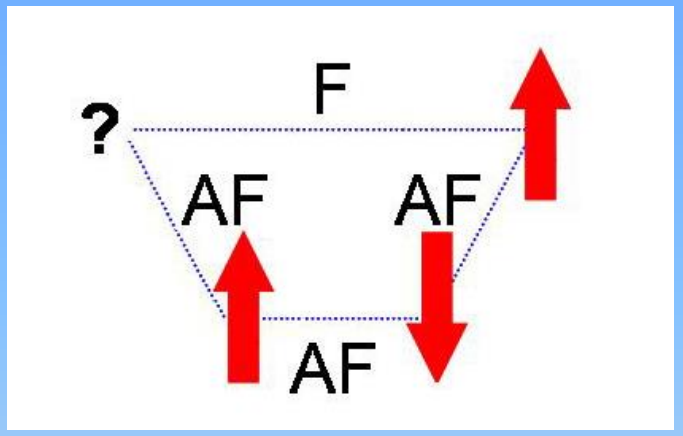




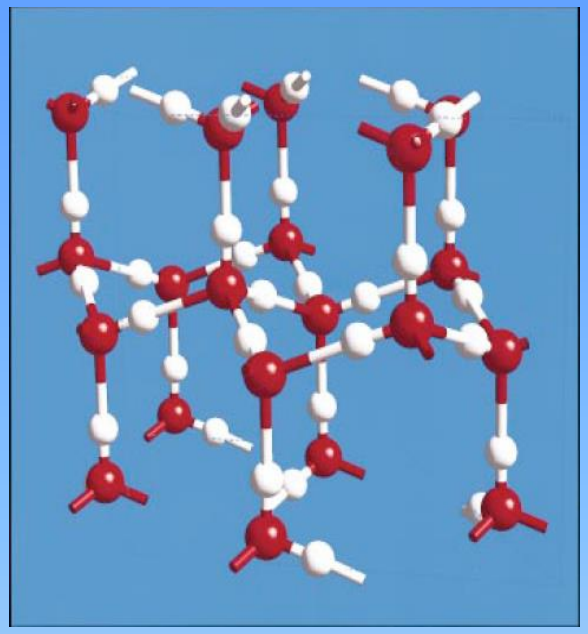


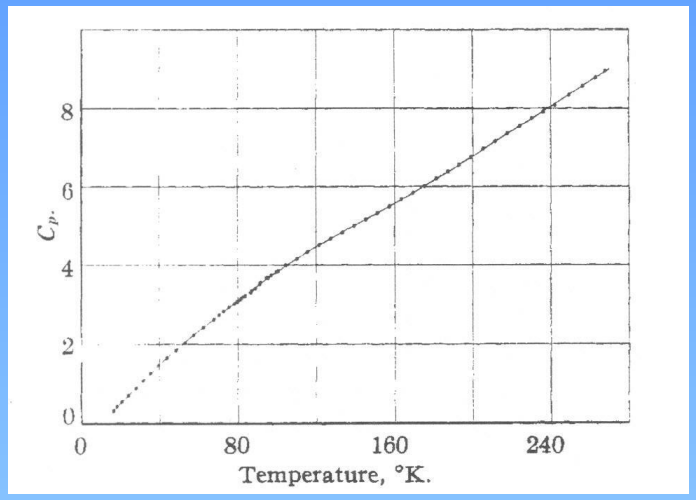
Spinová frustrácia





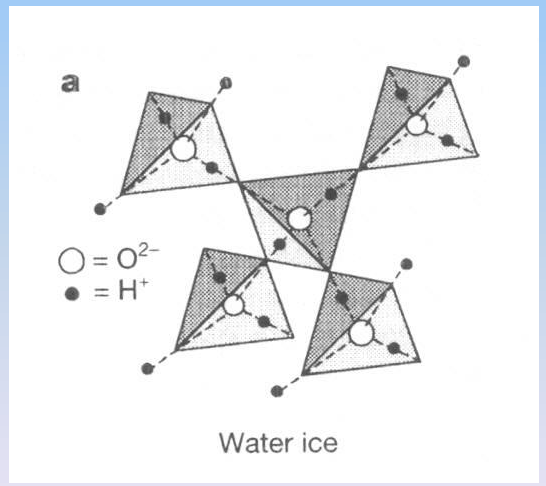
Vplyv spinovej frustrácie na základný stav, excitované stavy
$\Rightarrow$ existencia kritickej teploty



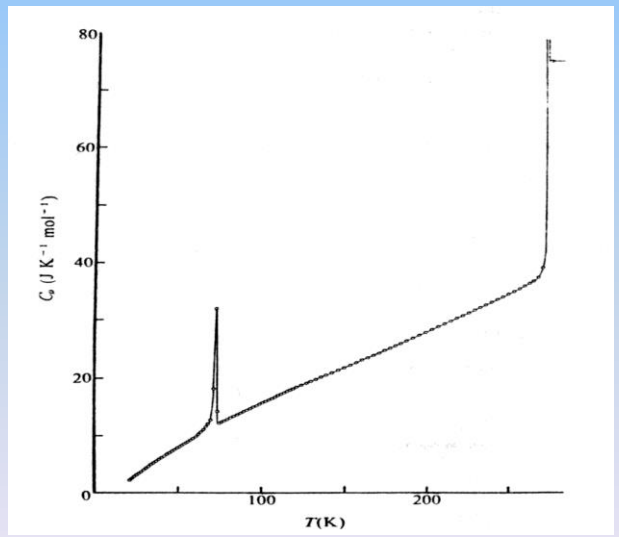


$$S = \int_0^\infty \frac{C(T)}{T} dT$$

T. Giague, Phys. Rev. (1933)



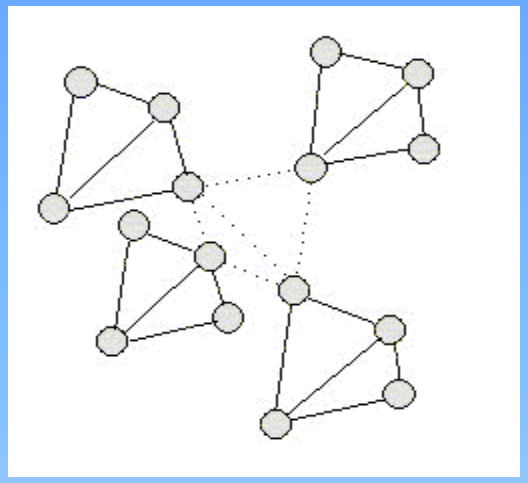
$$\Delta S = R \frac{1}{2} \ln\left(\frac{3}{2}\right)$$



W. Pauling, J. Am. Chem. Soc., (1935)

Y. Tajima, Nature, (1982)

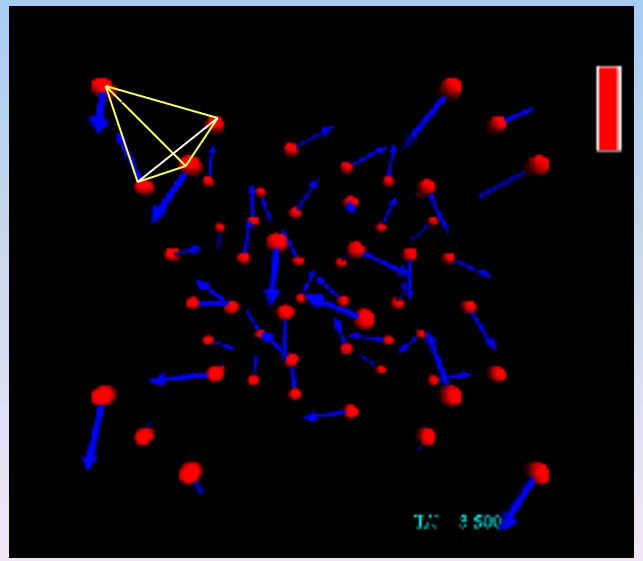
Pyrochlóry vzácnych zemín

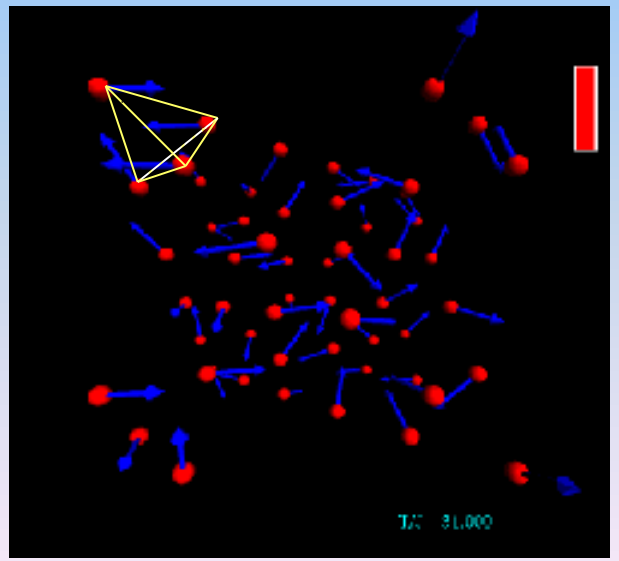


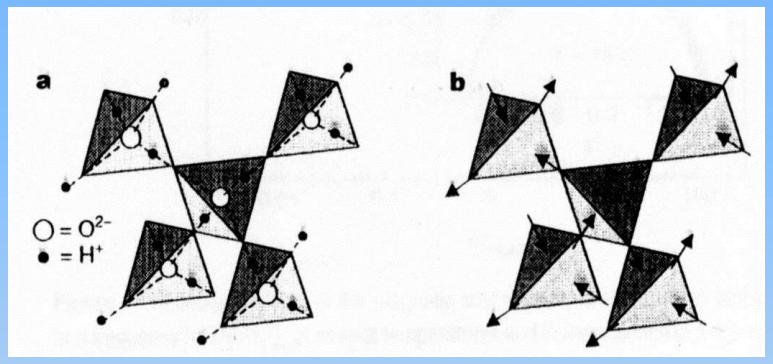
$Re_2 X_2 O_7$ - Re = Er, Ho, Dy, Y,
X = Ti, Sn, Mo

bežný feromagnet

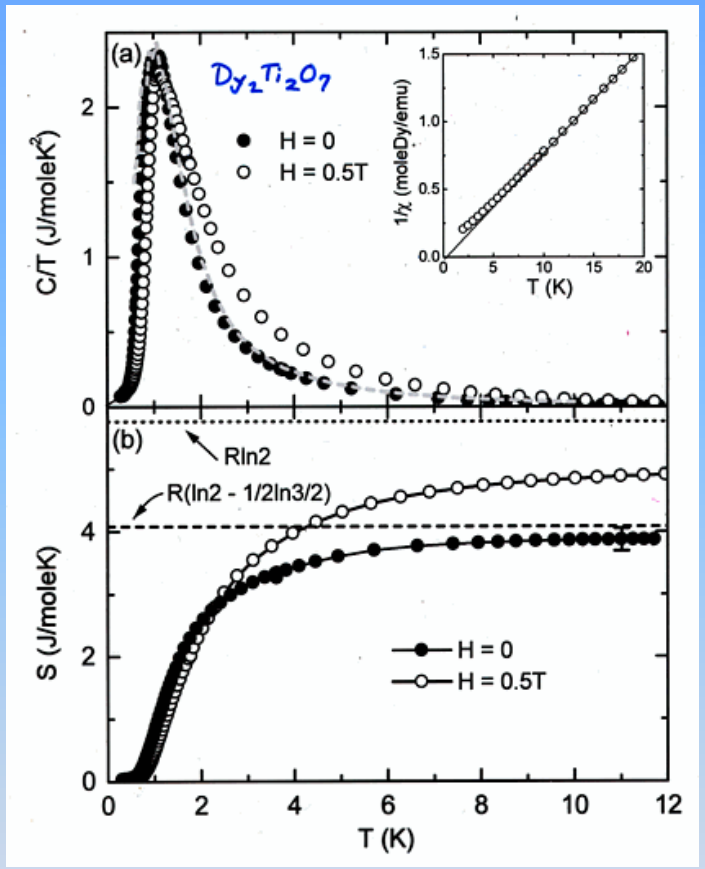
$Dy_2Ti_2O_7$
$Ho_2Ti_2O_7$







vodný ľad spinový ľad

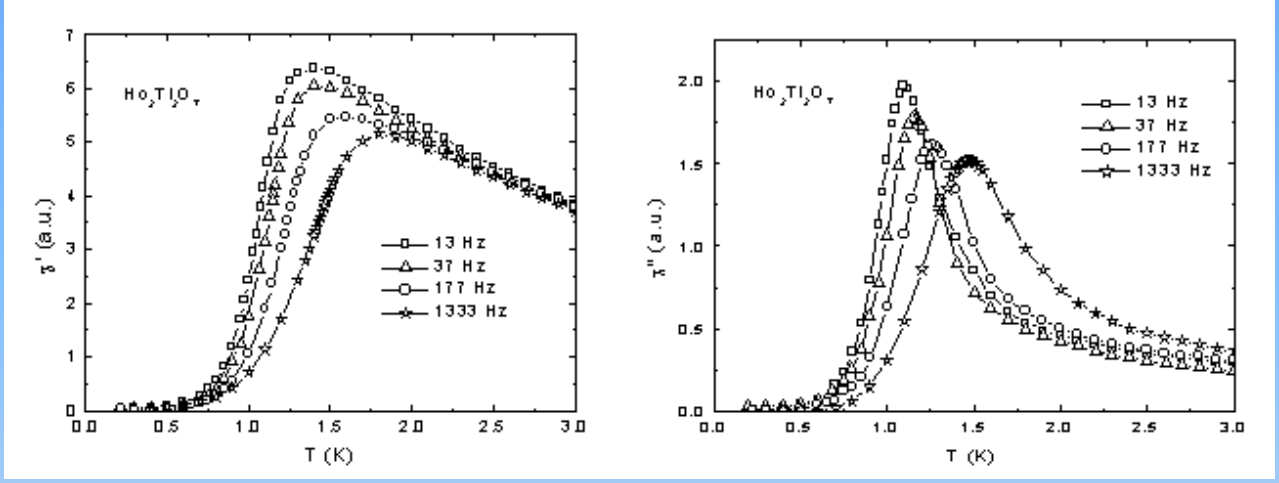


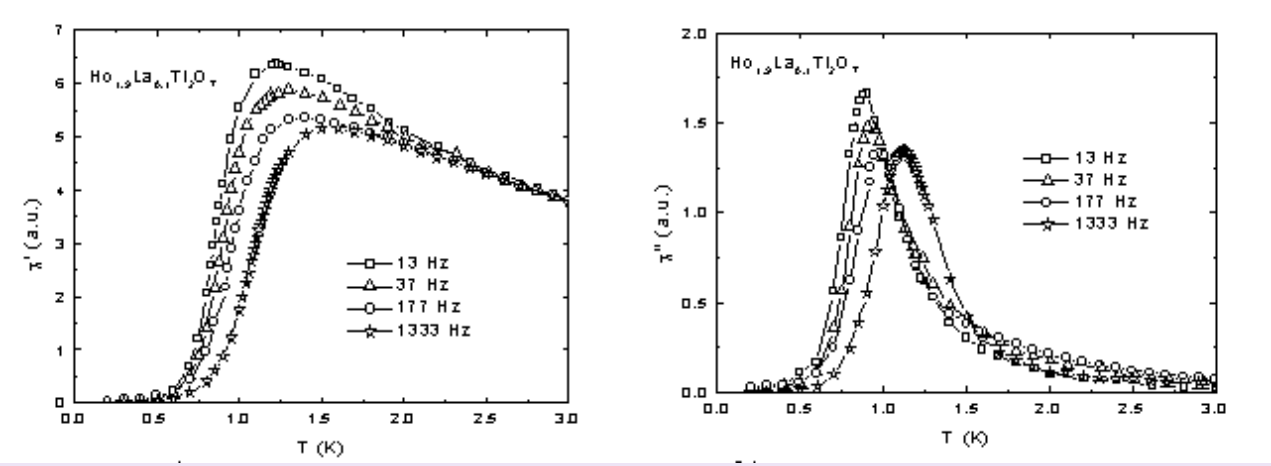
A. P. Ramirez, Nature, (1999)

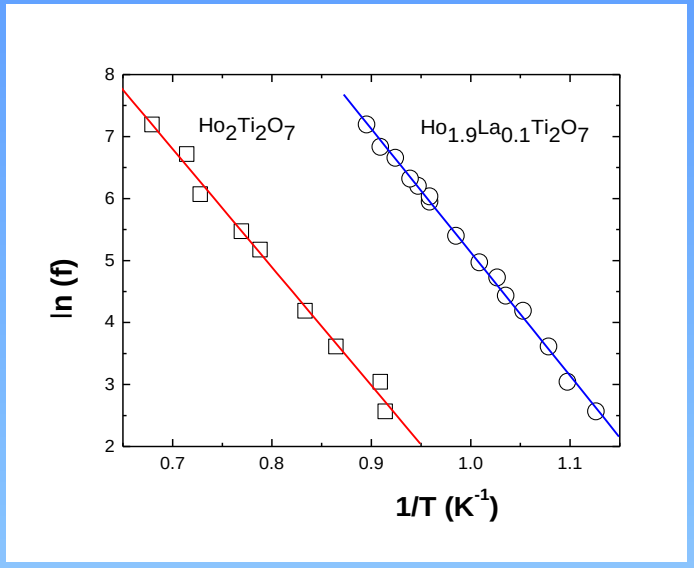
Pokiaľ možno s uvedenou analógiou zájsť ?

$\chi = dM/dH$

$\chi = \chi' + i\chi''$



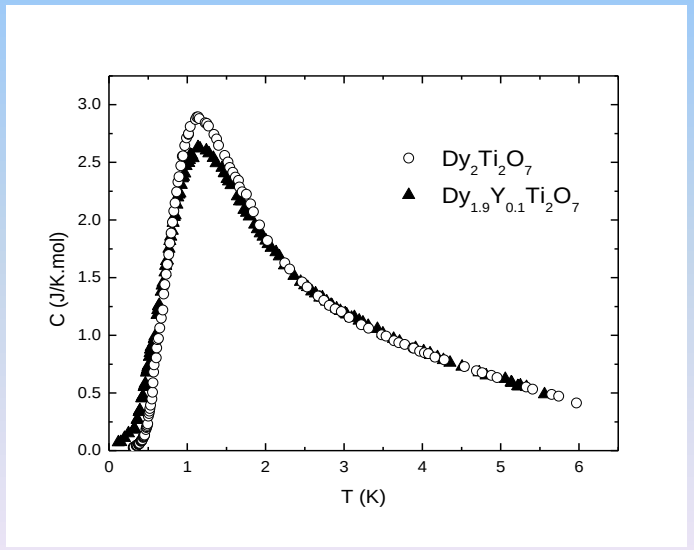


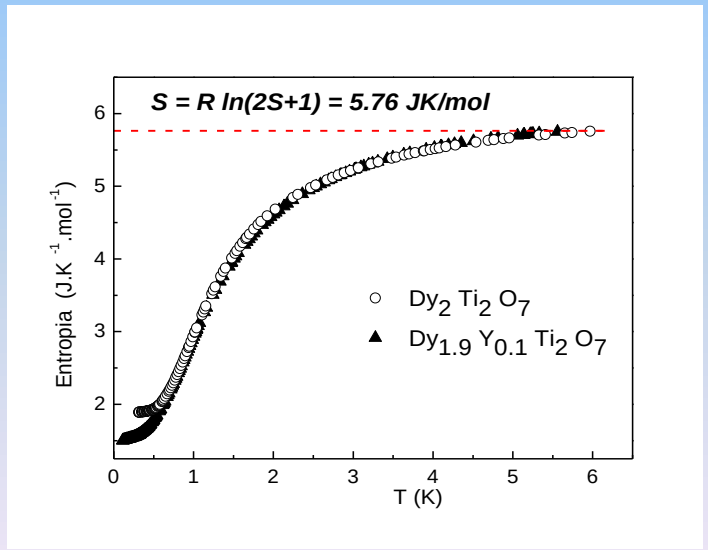


Arrheniov vzťah $\tau = \tau_0 \exp\left(\frac{E_B}{k_B T}\right)$

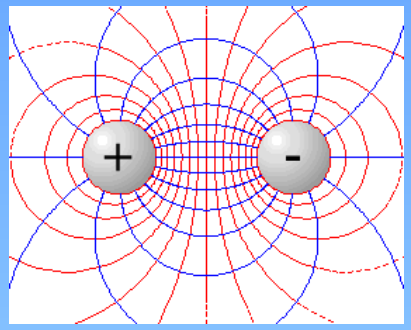
$E_B / k_B T \approx 20$ K

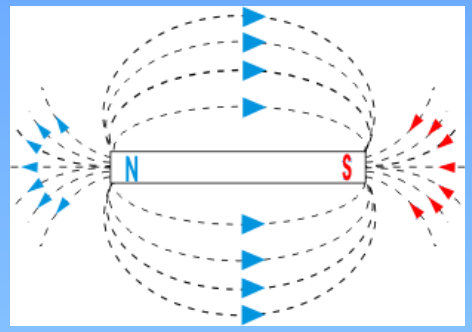
$\tau_0(Ho_2Ti_2O_7) \approx 150.\ \tau_0(Ho_{1.9}La_{0.1}Ti_2O_7)$

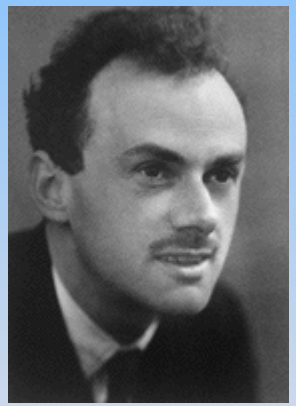




Diracove monopóly - teória







P. A. M. Dirac, Proc. Roy. Soc., (1931)

Quantised Singularities in the Electromagnetic Field

Our theory thus allows isolated magnetic poles, but the strength of such poles must be quantised, the quantum μ_0 being connected with the electronic charge e by

$$hc/e\mu_0 = 2. \qquad (9)$$

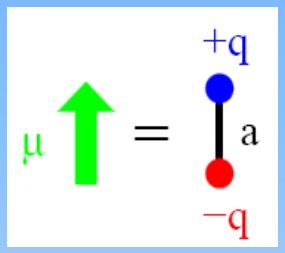
the laws of nature should be expressed in beautiful equations

$$\nabla \cdot \mathbf{E} = 4\pi\rho_e \qquad \nabla \cdot \mathbf{B} = 4\pi\rho_m \qquad -\nabla \times \mathbf{E} = \frac{1}{c}\frac{\partial \mathbf{B}}{\partial t} + \frac{4\pi}{c}\mathbf{j}_m \qquad \nabla \times \mathbf{B} = \frac{1}{c}\frac{\partial \mathbf{E}}{\partial t} + \frac{4\pi}{c}\mathbf{j}_e$$

Diracove monopóly v spinovom ľade

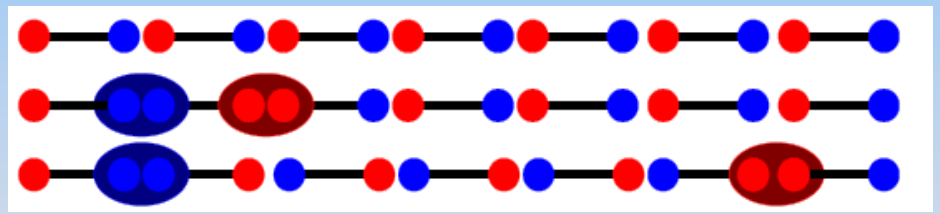
„činkový“ (dumbell) model

súbor interagujúcich dipólov



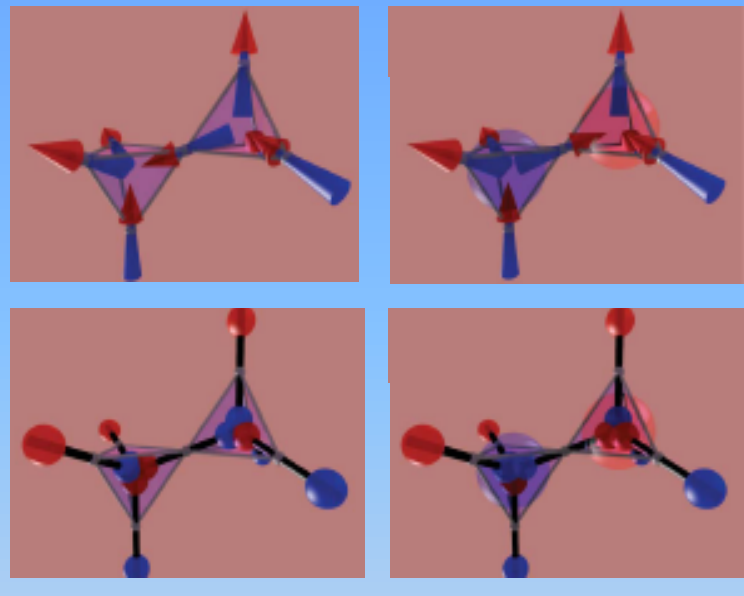
→

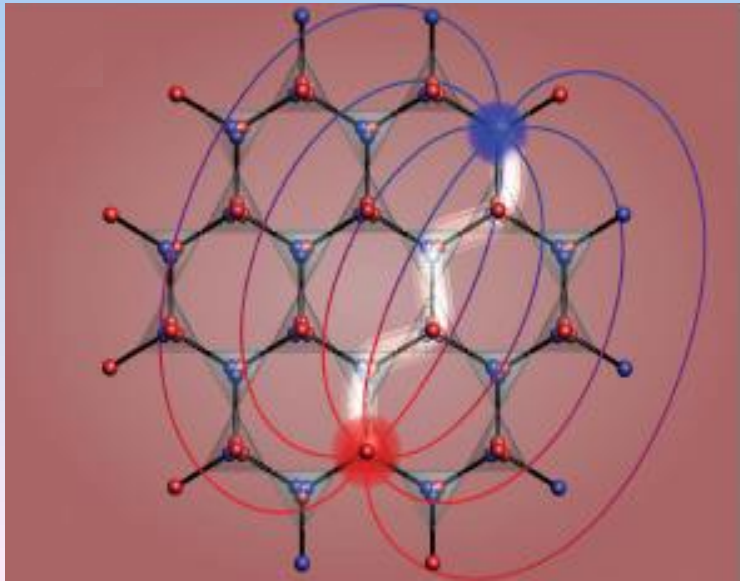
súbor magnetických
nábojov s kulombovskou interakciou



$$q_m = 2\mu/a$$

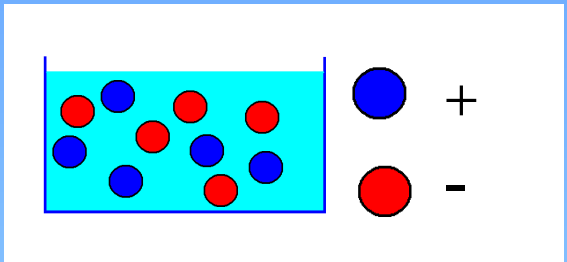
$$E(r) = -\frac{\mu_0}{4\pi}\frac{q_m^2}{r}$$



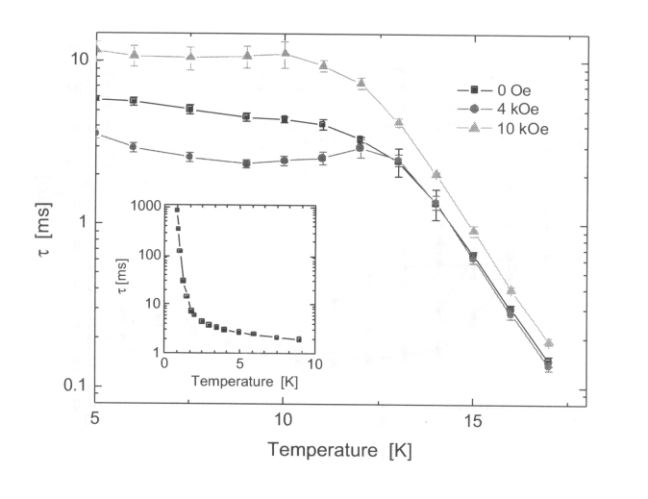


C. Castelnovo et al., Nature, (2008)

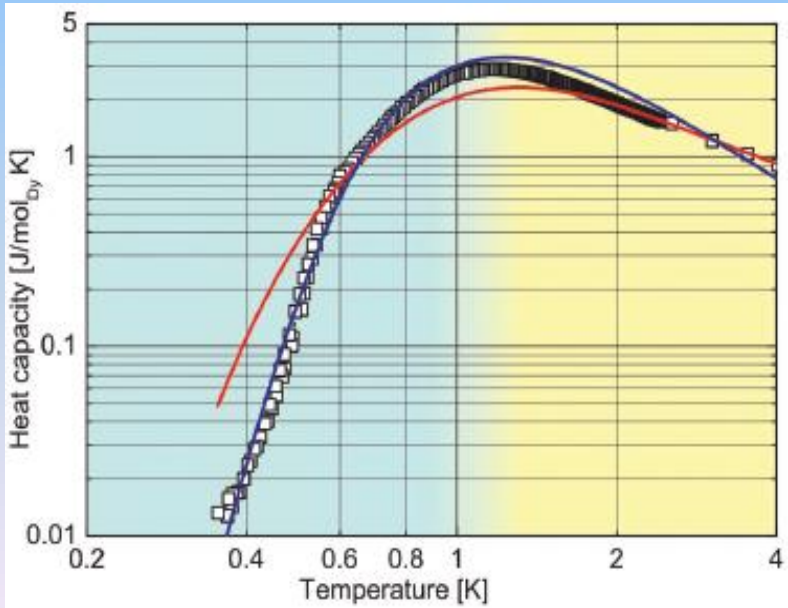
Debye - Hückelov model
Phys. Zeitschrift, (1923)



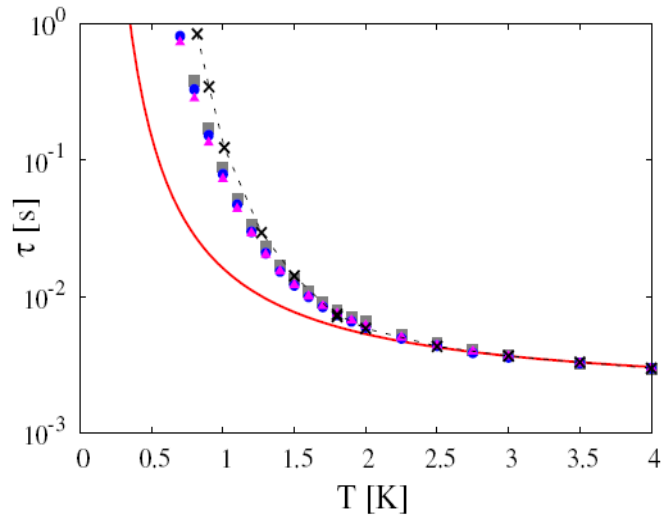
J. Snyder et al., PRL (2004)

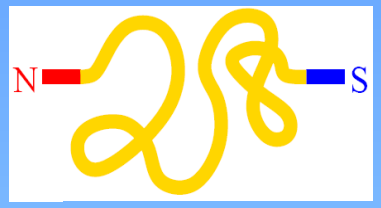


D. J. P.Morris et al., Science, (2009)

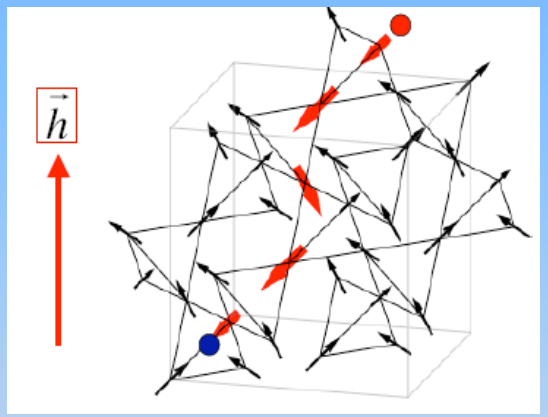


L. Jaubert et al, Nature, (2008)

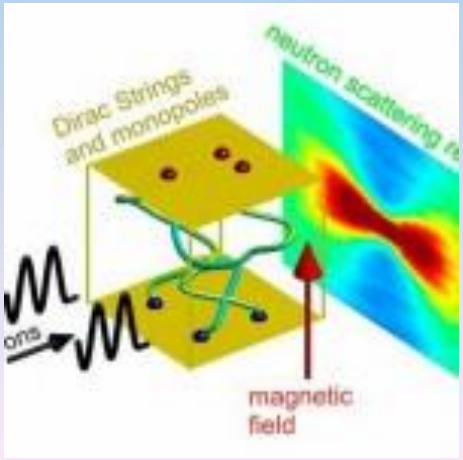


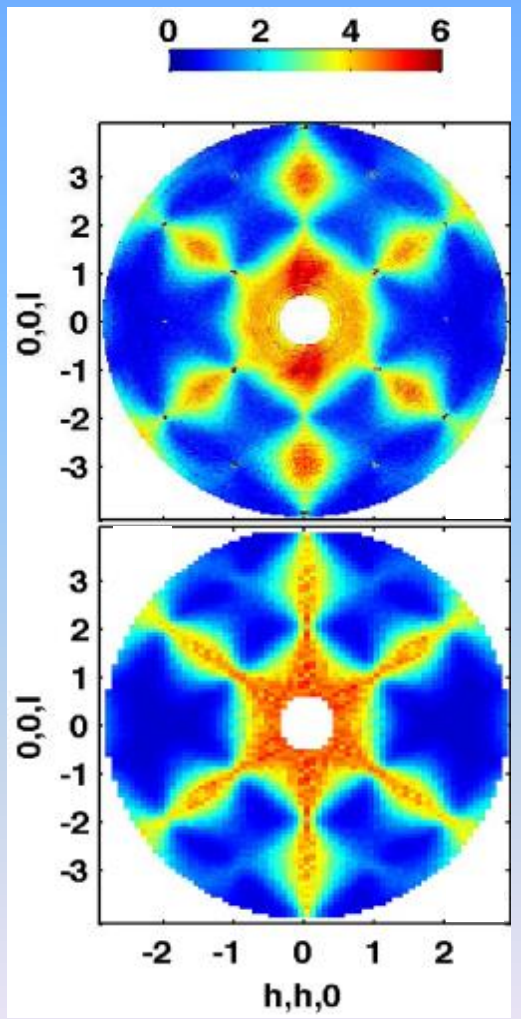


B = 0



B << J
B || [100]

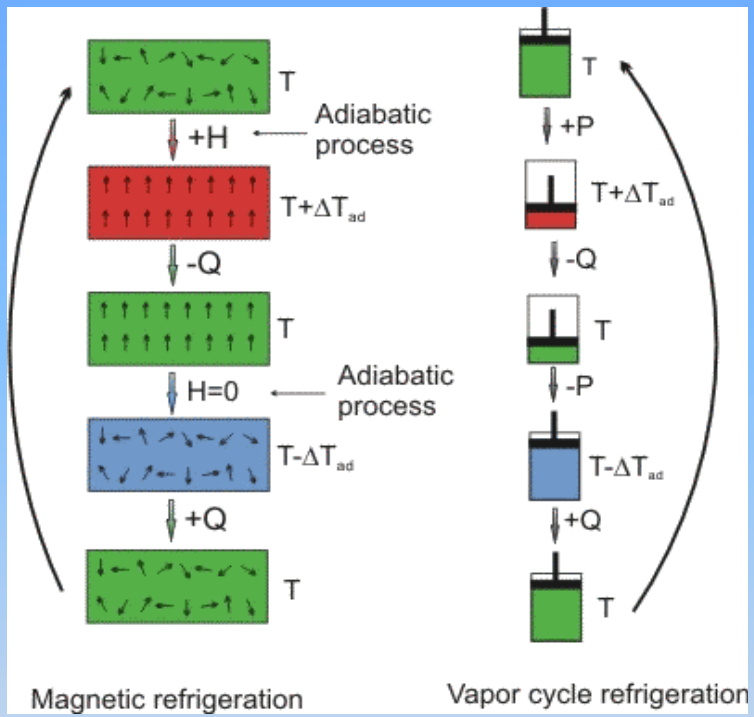




$Ho_2Ti_2O_7$

D. J. P. Morris et al., Science (2009)

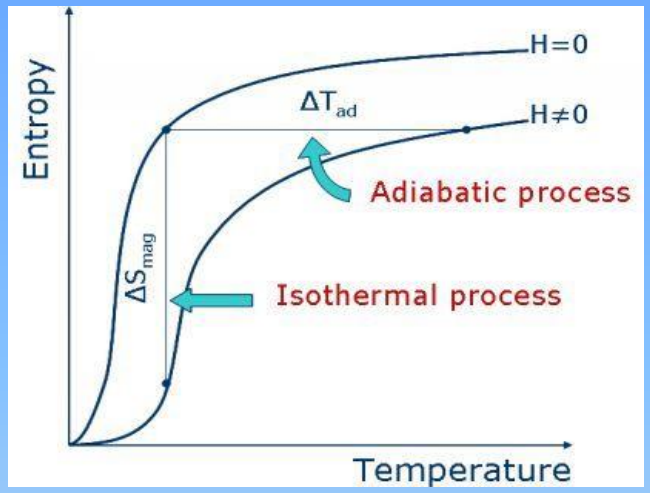
Magnetokalorický jav

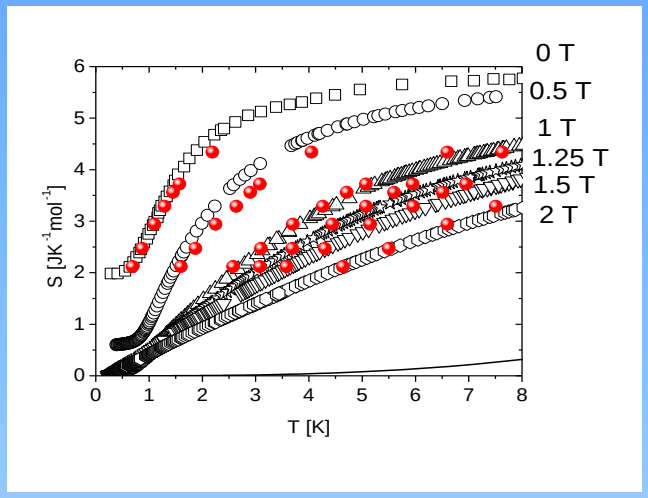


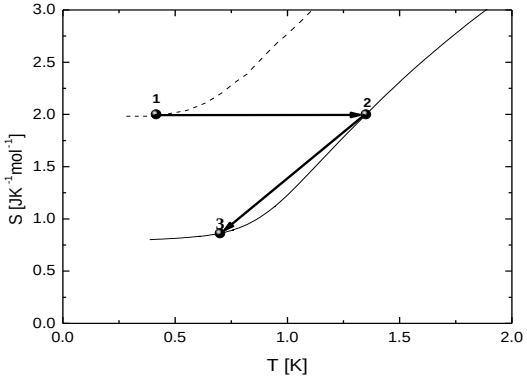
$$\left(\frac{\partial S}{\partial H}\right)_T = \left(\frac{\partial M}{\partial T}\right)_H$$

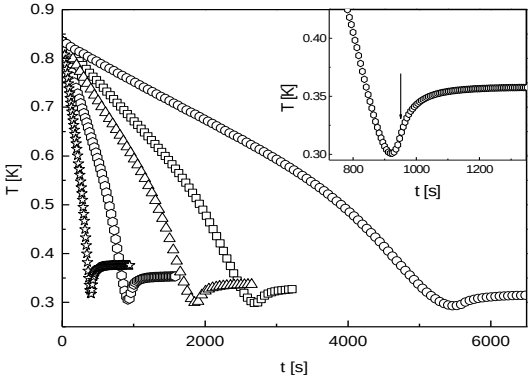
$$\left(\frac{\partial T}{\partial H}\right)_S = -T\frac{(\partial S/\partial H)_T}{C}$$

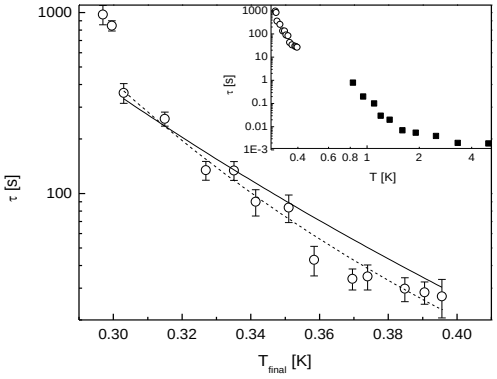
Štúdium magnetokalorického javu na spinovom ľade $Dy_2Ti_2O_7$



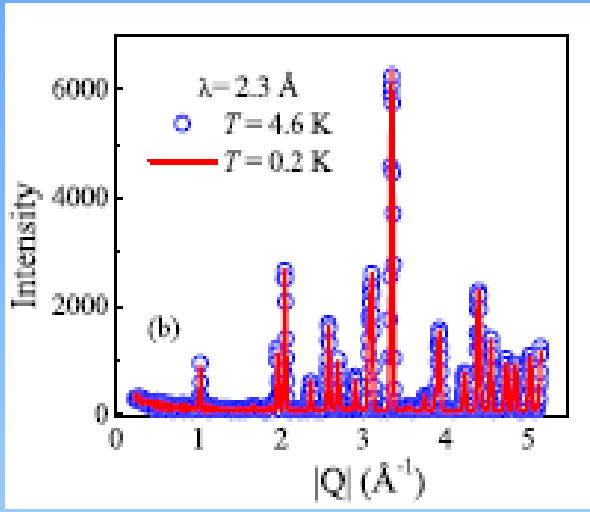


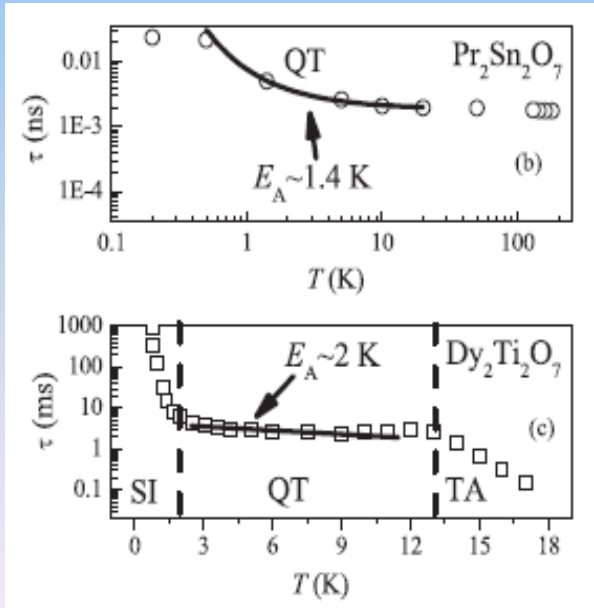


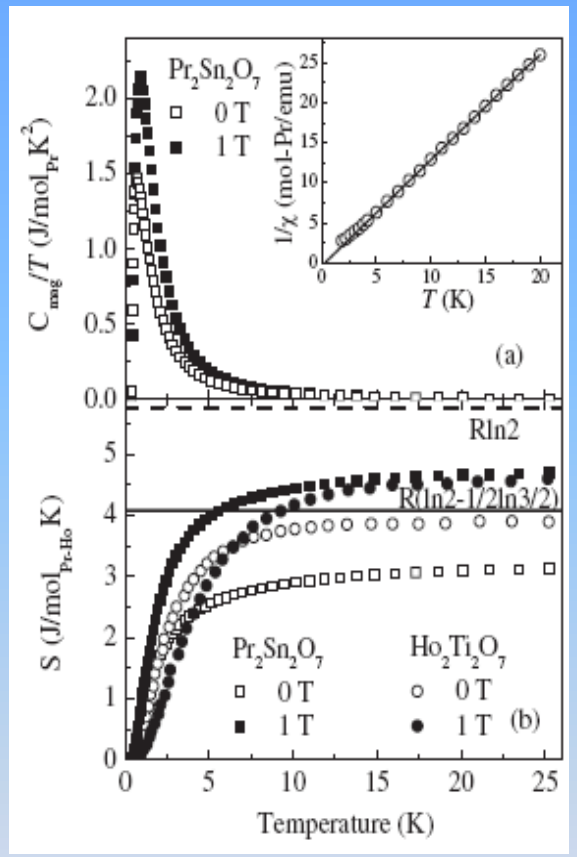




$Pr_2Sn_2O_7$ – dynamický spinový ľad

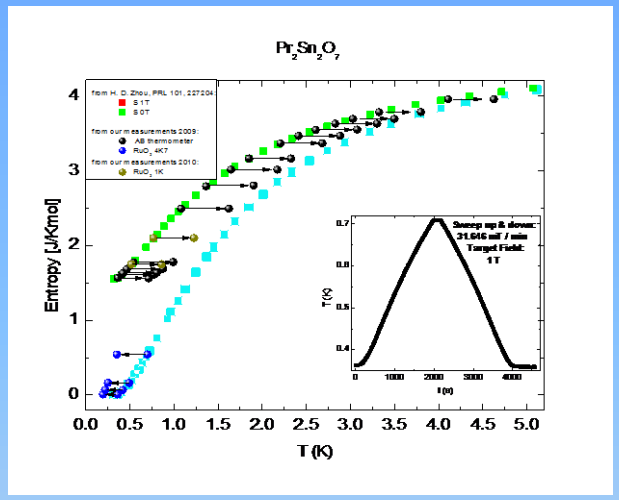




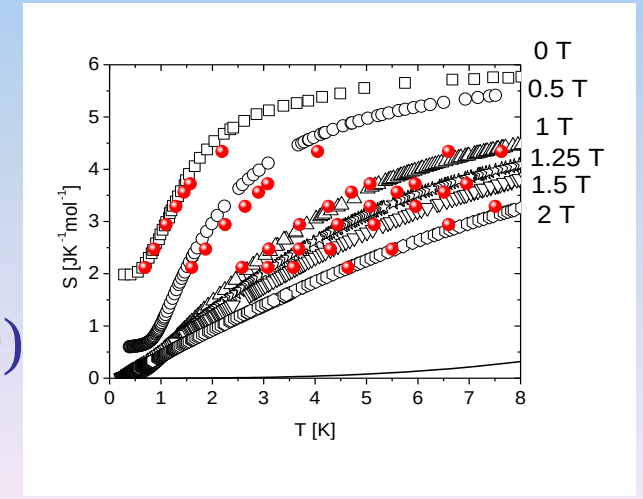


H. D. Zhou, PRB (2010)

$Pr_2Sn_2O_7$



$Dy_2Ti_2O_7$



Záver:

1. Spinový ľad predstavuje nekonvenčný magnetický systém ponúkajúci analógie s inými objektmi neživej prírody
2. Excitované stavy v (statickom) spinovom ľade môžu byť popísané použitím predstavy Diracových monopólov
3. Frustrácia v spinovom ľade vedie na nekonvenčné magnetické a relaxačné vlastnosti
4. Doposiaľ nejestvuje vysvetlenie pre objasnenie magnetokalorického javu na spinovom ľade.

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APVV, VEGA

Ďakujem za pozornosť