



Feromagnetne tekočokristalne suspenzije

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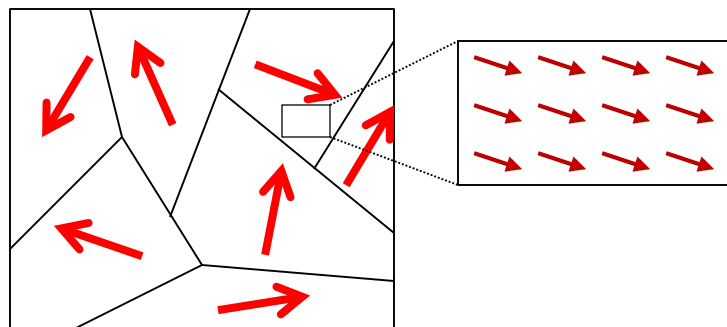
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Feromagnetizem v trdnih snoveh

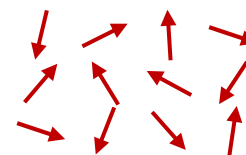
feromagnetna

T_{Curie}

paramagnetna

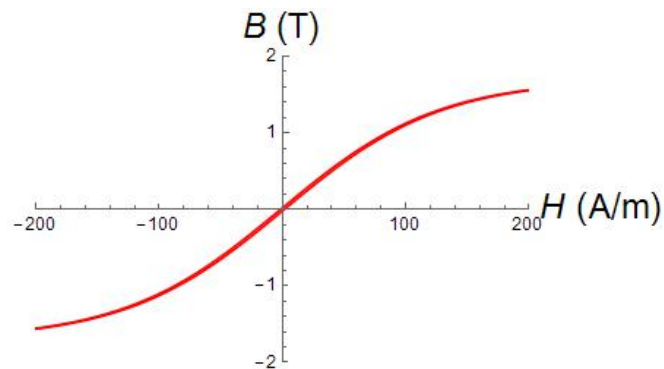
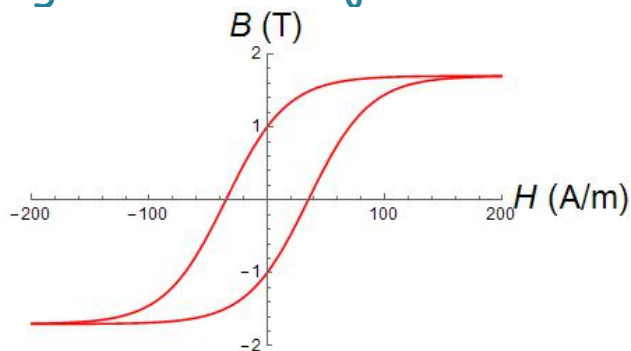


1043 K (Fe)



- magnetni momenti znotraj domene urejeni v isto smer, vmes domenske stene
- magnetilna krivulja ima histerezo

- magnetni momenti neurejeni
- magnetilna krivulja nima histereze



Magnetni delci v tekočem kristalu

Stara napoved: ferromagnetizem se lahko pojavi v urejeni tekočini, če združimo magnetno tekočino (ferofluid) in tekoči kristal.

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TOME 31, JUILLET 1970, PAGE 691

THEORY OF MAGNETIC SUSPENSIONS IN LIQUID CRYSTALS

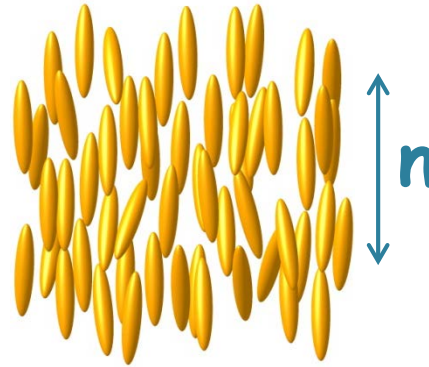
F. BROCHARD and P. G. de GENNES

Physique des Solides (*), Faculté des Sciences, 91-Orsay

(Reçu le 20 mars 1970, révisé le 15 avril 1970)



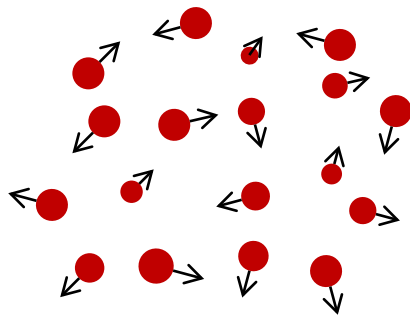
Nematični tekoči kristali



- anizotropni $\underline{\epsilon}$, χ
 $\epsilon_a \sim 10$, $\chi_a \sim 10^{-6}$
- optična os $\parallel n$
 $n_e - n_o \sim 0.2$

Ferofluidi

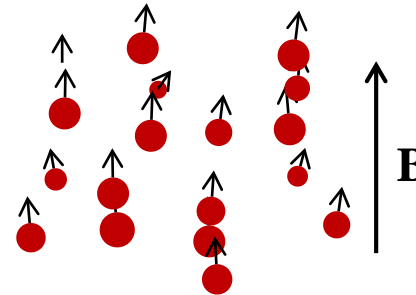
- Koloidi magnetno enodomenskih nanodelcev v izotropni tekočini
- Stabilnost: velikost delcev in polidisperznost



$$\mathbf{B} = 0$$

$$\mathbf{M} = 0$$

$$\left\langle \frac{\mu_0 \mathbf{p}_{mi} \cdot \mathbf{p}_{mj}}{4\pi R_{ij}^3} \right\rangle_{orient} \leq k_B T$$



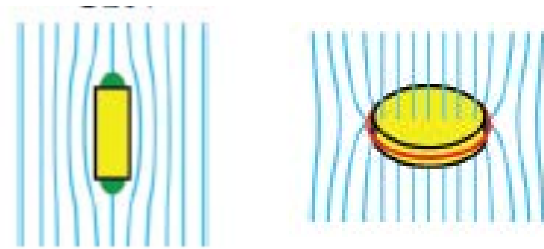
$$\mathbf{M} = \chi \mathbf{B} / \mu_0$$

$$\left\langle \frac{\mu_0 \mathbf{p}_{mi} \cdot \mathbf{p}_{mj}}{4\pi R_{ij}^3} \right\rangle_{orient} \geq k_B T$$



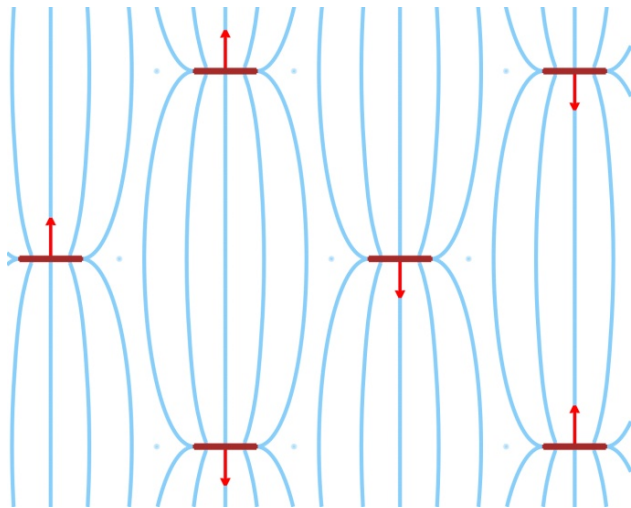
"Feronematični" TK

Anizotropni delec se v nematiku orientira v določeno smer, odvisno od oblike in površinskih lastnosti.

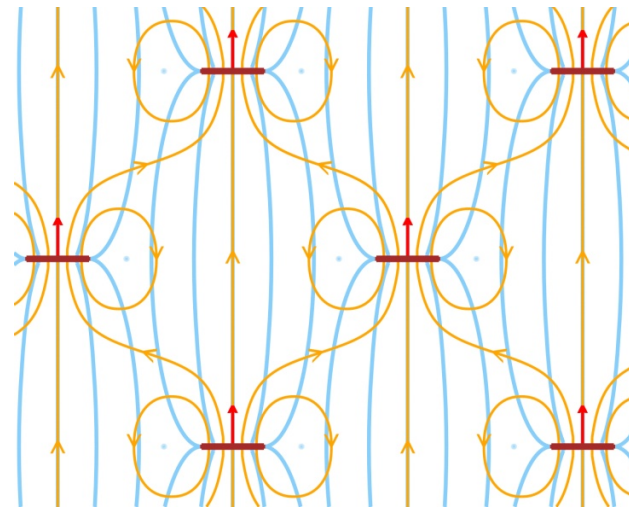


Magnetni anizotropni delci

- paramagnetna ($B = 0, M = 0$) ali feromagnetna ($B = 0, M = M_s$)



n



n M

Izkaže se, da je za stabilnost feromagnetne faze ključna oblika delcev, podolgovati agregirajo, ploščice pa ne.



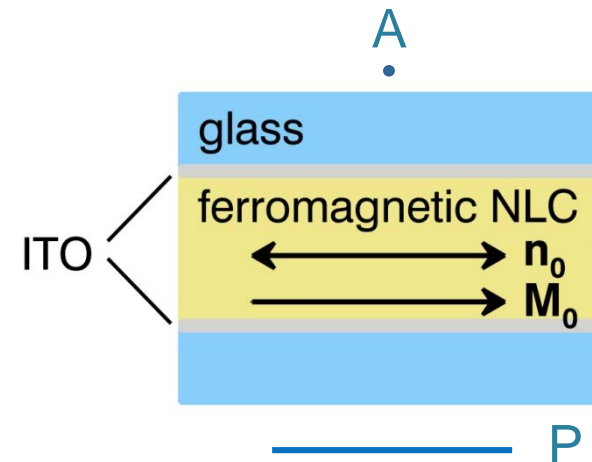
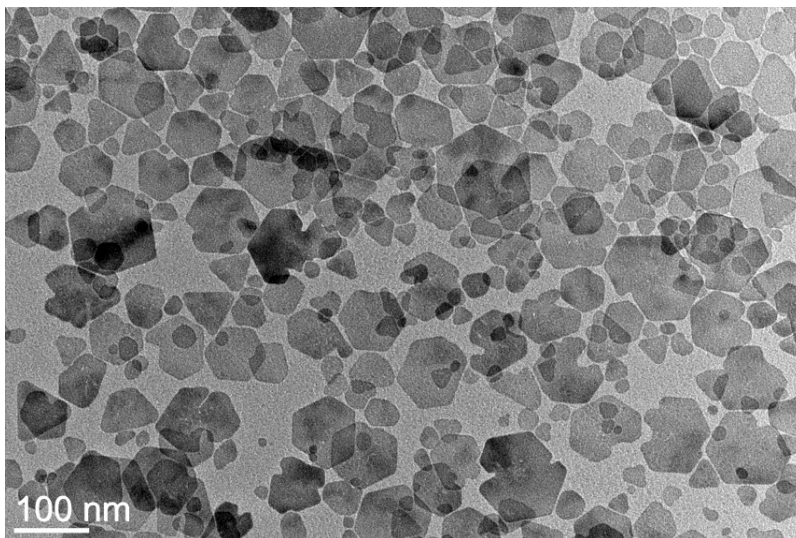
Ferromagnetne suspenzije

Nematik 5CB, $T_{NI}=35\text{ }^{\circ}\text{C}$

Ferromagnetne nanoploščice: BaHF dopirane s Sc^1 , $M_{s,\text{mass}} = 32\text{ Am}^2/\text{kg}$

$D = 5\text{ nm}$, $2R_{\text{avg}} = 70\text{ nm}$, $SD = 38\text{ nm}$, $\Phi = 3 \cdot 10^{-4}$

Surfaktant: dodecilbenzen sulfonska kislina \rightarrow pravokotna orient.

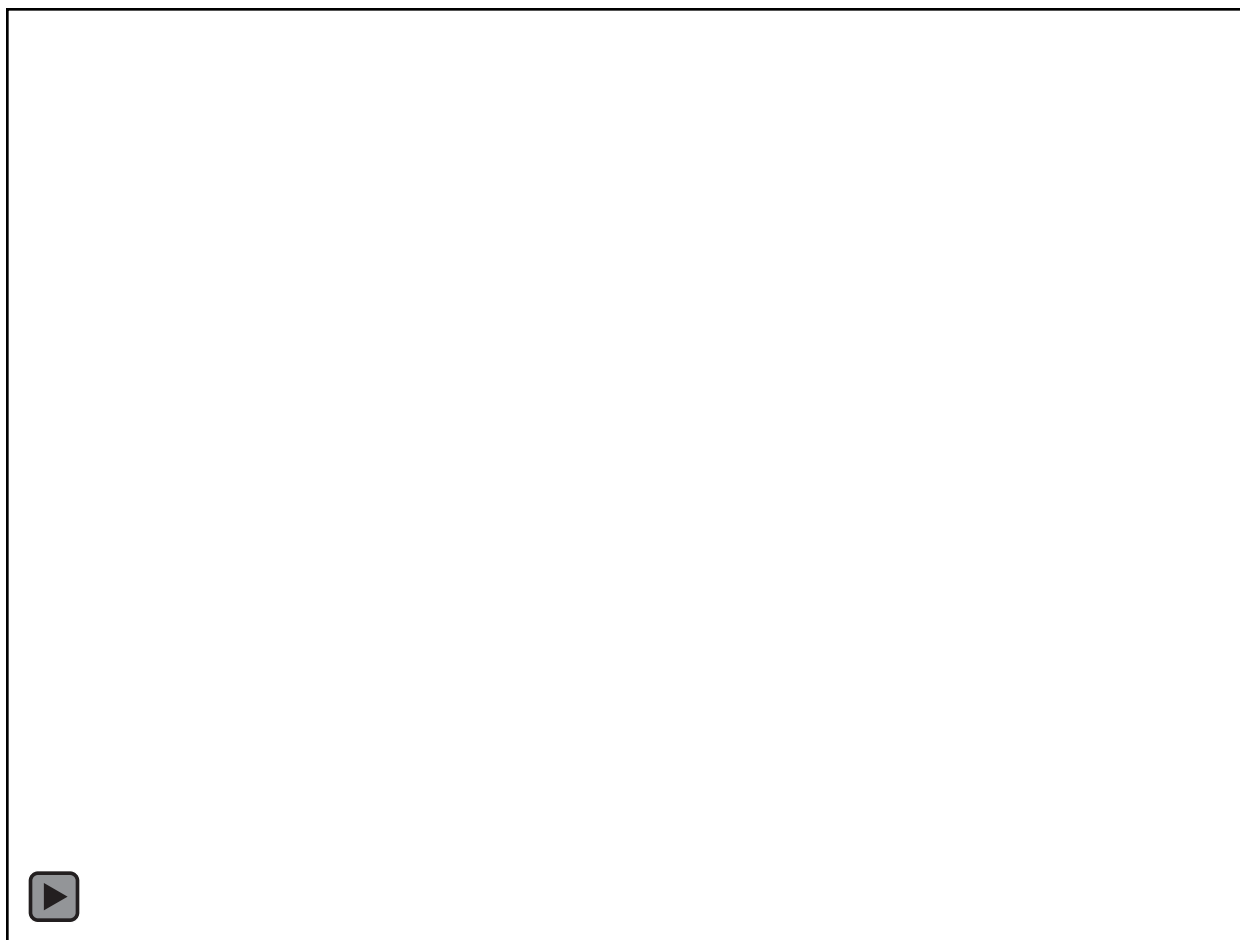


¹D. Lisjak, M. Drogenik, *Crystal Growth & Design* (2012), doi:10.1021/cg301227r.



Rast magnetnih domen

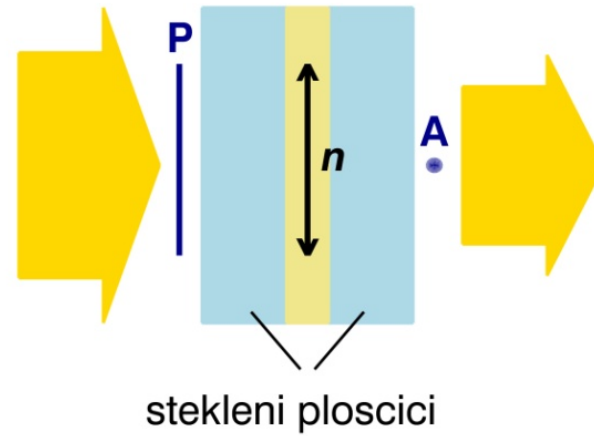
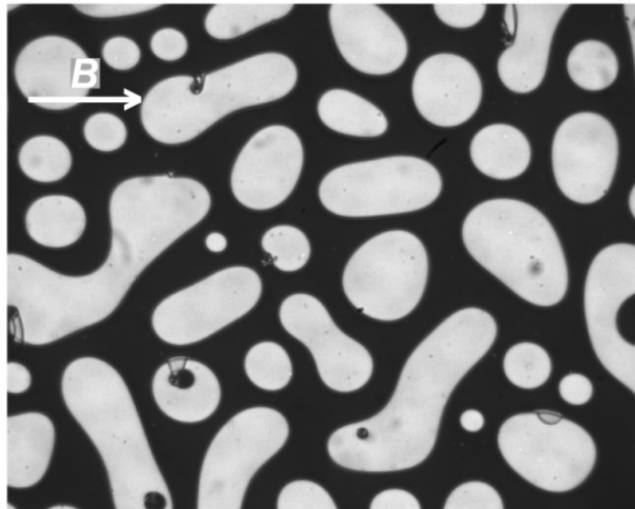
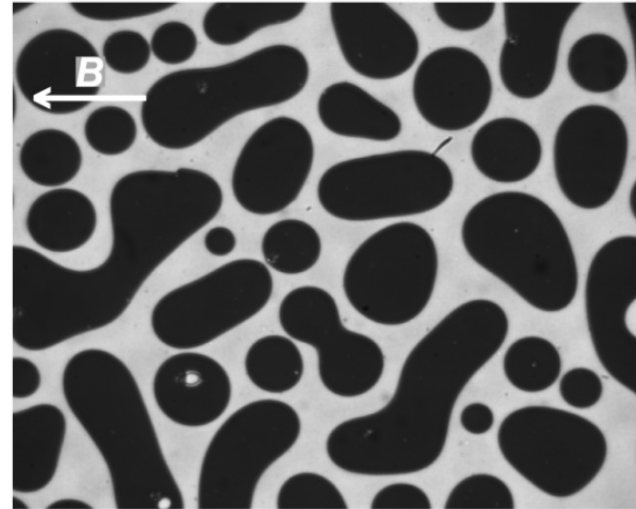
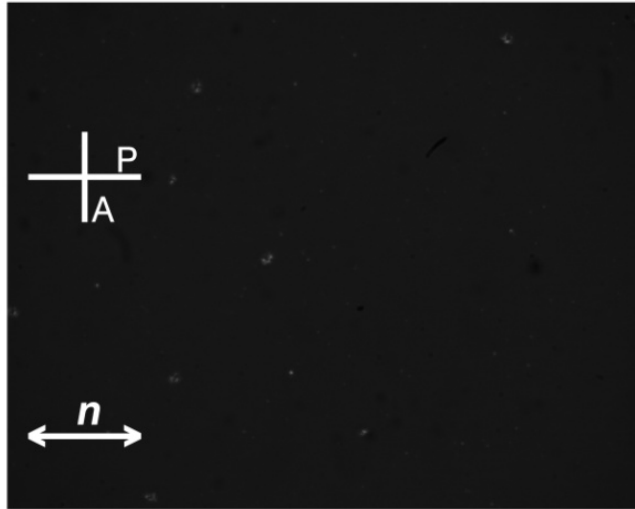
B □ n



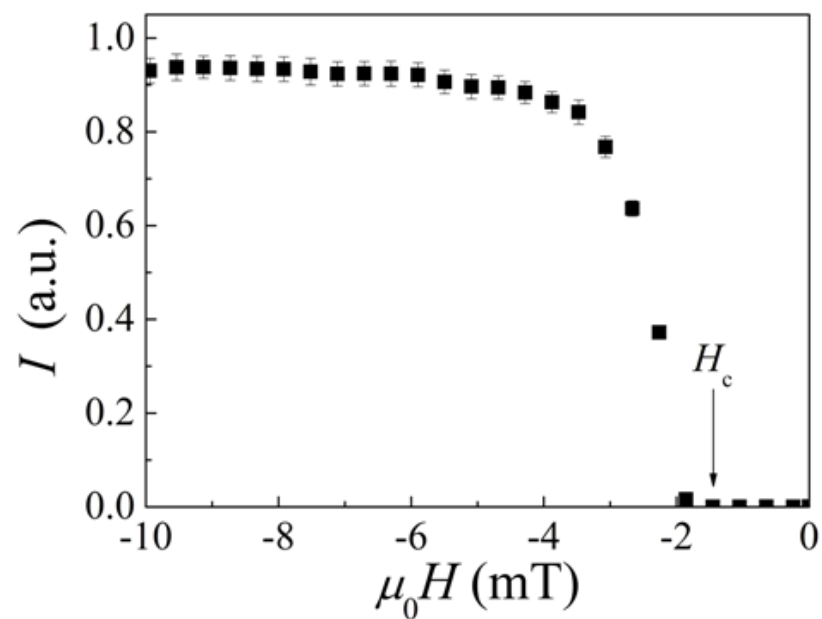
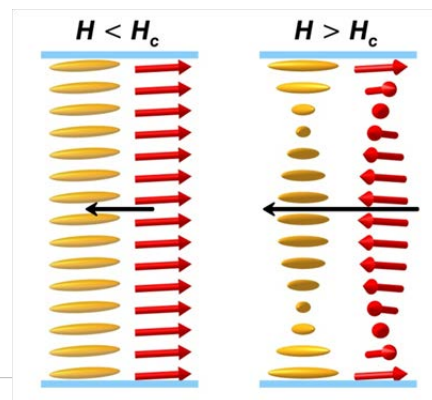
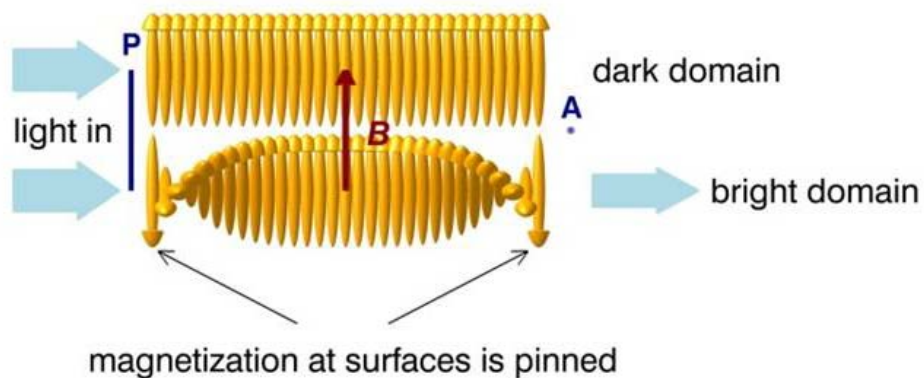
0.84 mm



Preklop domen



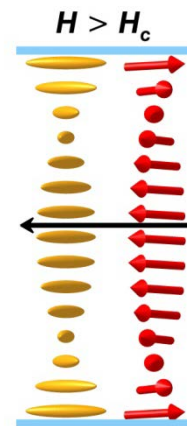
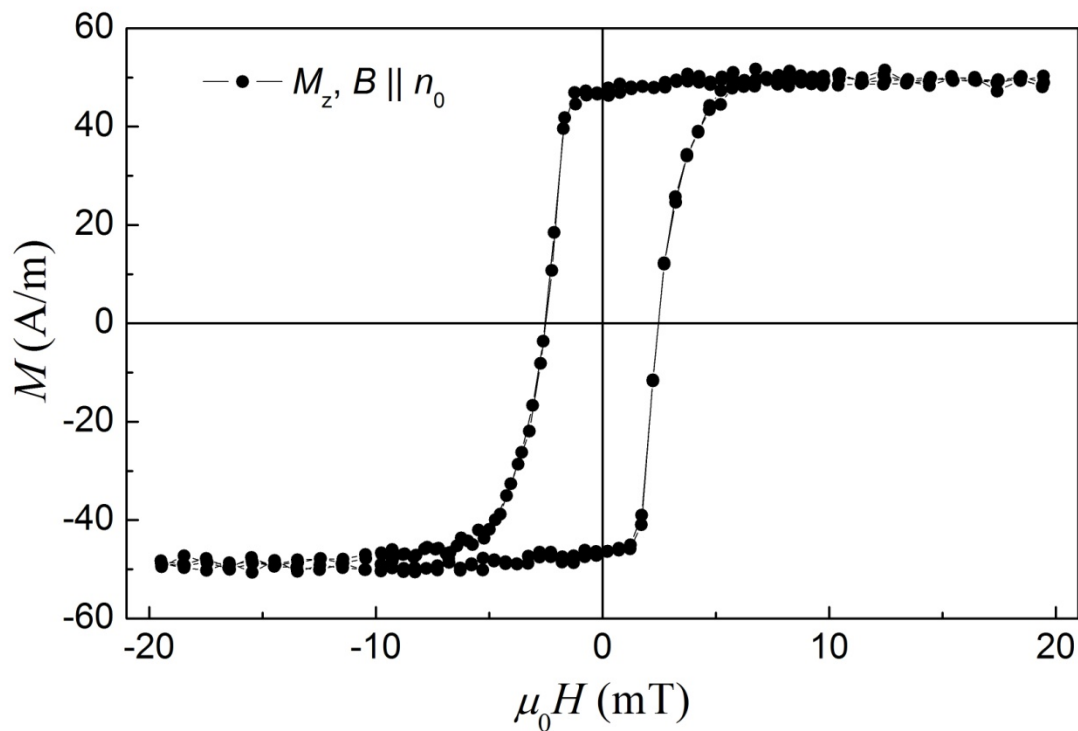
Preklop domen(2)



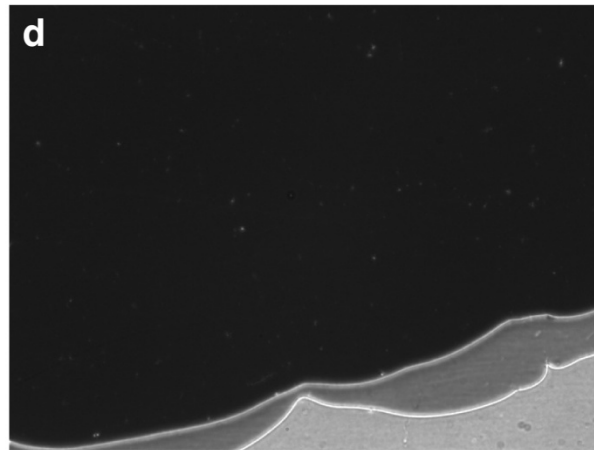
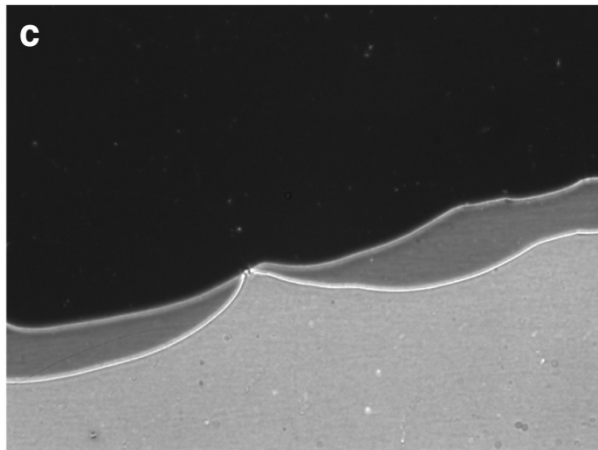
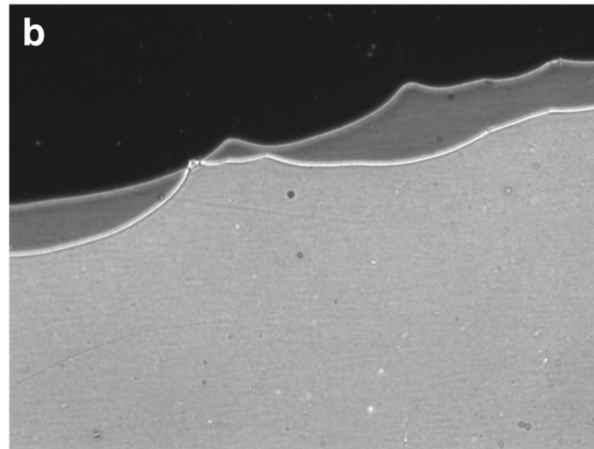
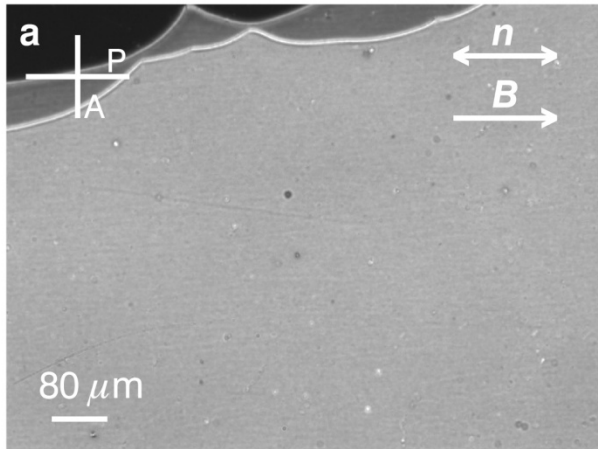
Magnetna histereza

- Enodomenski vzorec, $M_s \approx 50 \text{ A/m}$

Kritično polje $\sim 1.5 \text{ mT}$

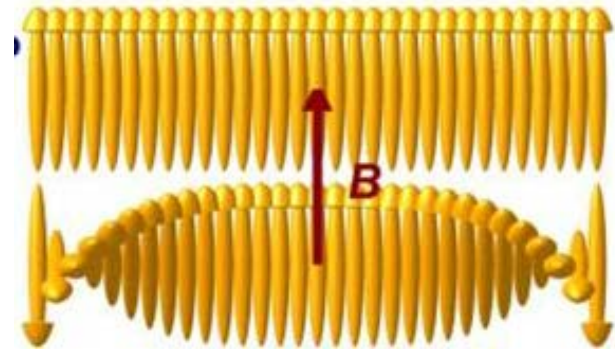


Domenske stene



Bele črte:
 π - stene

$$\Delta t = 10s$$



Zaključek

- Suspenzija magnetnih ploščic v nematiku ima **makroskopsko magnetizacijo v odsotnosti zunanje polja**.
- Opazili smo **dva tipa domen z nasprotnima magnetizacijama vzdolž direktorja**.
- Magnetno **histerezo** opazimo tudi v monodomenskem vzorcu. Magnetizacija se začne obračati že **pri majhnih poljih**. Popoln obrat magnetizacije se zgodi **s potovanjem površinskih domenskih sten**.

Raziskave v teku in načrti: študij domenskih sten in defektov, dinamika sklopljenih n in M , mikroskopska struktura suspenzije, stabilnost feromagnetne faze (temperatura, velikost ploščic), zvite faze ...

A. Mertelj, D. Lisjak, M. Drofenik, and M. Čopič, *Nature* **504**, 237 (2013).

A. Mertelj, N. Osterman, D. Lisjak, and M. Čopič, *Soft Matter*, 10.1039/C4SM01625D (2014).





Hvala za pozornost!