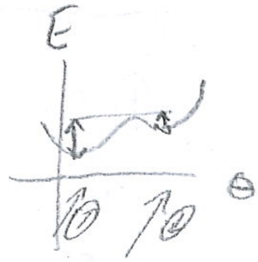
4 Remanence

Review

$$E = -\mu_0 M_S V H \cos\theta + \frac{1}{2}\mu_0 M_S V H_K \sin^2\theta$$

$$\Delta E = \frac{1}{2}\mu_0 M_S V H_K \left(1 \pm \frac{H}{H_K}\right)^2$$



relaxation time: $\tau = \frac{\tau_0}{(2)} \exp\left\{\frac{\mu_0 M_S V H_K}{2kT}\right\}$ ← $\frac{\text{energy barrier}}{\text{thermal energy}}$

(2) ↗ only 0 field

spontaneous magn. for magnetite: $M_S(T) \cong M_S(0°C) \cdot \sqrt{1 - \frac{T}{T_c}}$

$M_S(0°C)$ ↑ 480 kAm²; T_c ↑ 580°C

shape anisotropy: $H_K = N \cdot M_S$

magnetization vs. time: $M(t) = M_{eq} + (M_0 - M_{eq}) e^{-t/\tau}$

$\Rightarrow V = \frac{1}{4} a^3$

Excel relaxation times

μ_0	$M_S(0)$	T	T_c	$M_S(T)$	N	H_K	a	k	τ_0	...
$4\pi \cdot 10^{-7}$	480 000	20	580	$M_S(0) \cdot \sqrt{1-\frac{T}{T_c}}$	0.5	$N M_S$	10	$1.38 \cdot 10^{-23}$	10^{-10}	
							15			
							20			
							25			

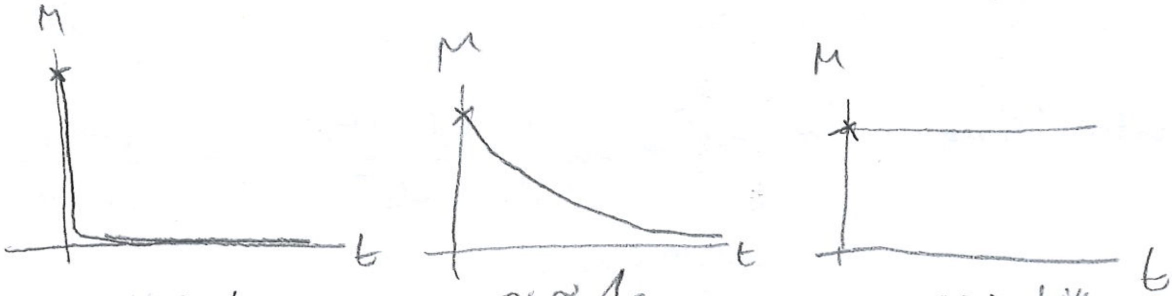
...	ΔE	kT	τ (relax)
	$\mu_0 M_S(T) H_K V$	$k_B (T+273)$	$\tau_0 \exp\left(\frac{\Delta E}{kT}\right)$

Remanence

Desmos: $M(t) = M_{eq} + (M_0 - M_{eq}) e^{-t/\tau}$

($M_0 \uparrow 1$, $M_{eq} \uparrow 0$)

Put in relaxation times for 10, 15, 20, 25 nm, etc



$\tau \ll 1s$ — "Super-paramagnetic" (SP)

$\tau \sim 1s$ — "relaxation"

$\tau \gg$ billions of years — "blocked"

CRM { small V : $\tau \ll 1s$ ⟶ <u>SP</u>
 large V : $\tau \gg$ billions of years ⟶ <u>blocked</u> }

IRM { small H_K : $\tau \ll 1s$ ⟶ <u>SP</u>
 large H_K : $\tau \gg$ billions of years ⟶ <u>blocked</u> }

TRM { low T : $\tau \gg$ billions of years ⟶ <u>blocked</u>
 high T : $\tau \ll 1s$ ⟶ <u>SP</u> }

VRM (intermediate T:
 → τ = 1s, 100s, days, years)

Thermal remanent magnetization: TRM (T)
Chemical remanent magnetization: CRM (V)
Viscous remanent magnetization: VRM (t)
Isothermal remanent magnetization: IRM (H, H_K)
Depositional remanent magnetization: DRM

$M(t) = M_{eq} - (M_0 - M_{eq}) \underline{\exp}\{-t/\tau_0 \underline{\exp}[\mu_0 M_s V H_K / 2kT]\}$

TRM

Excel: $\tau(T)$ for 25 nm, 20 nm, 17 nm

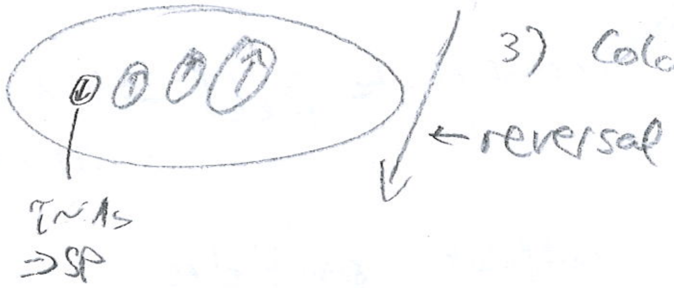
(axis limits 1 s → 5 bn years, log)

Nomogram

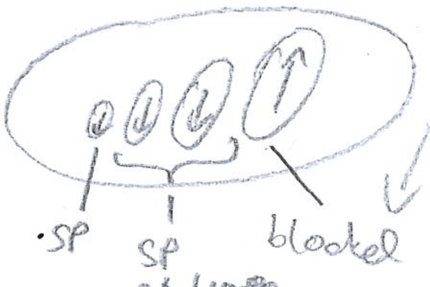
Real sample:

1) Hot ($T > T_c$)

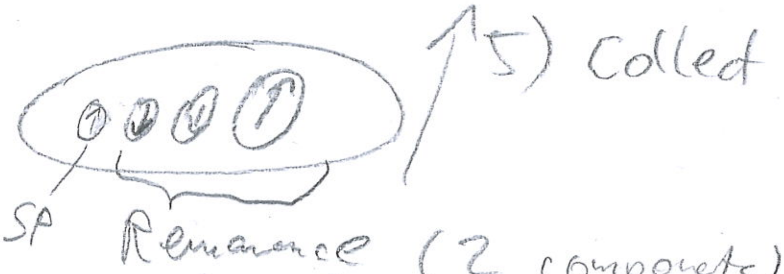
2) Hot (T = 579°C)



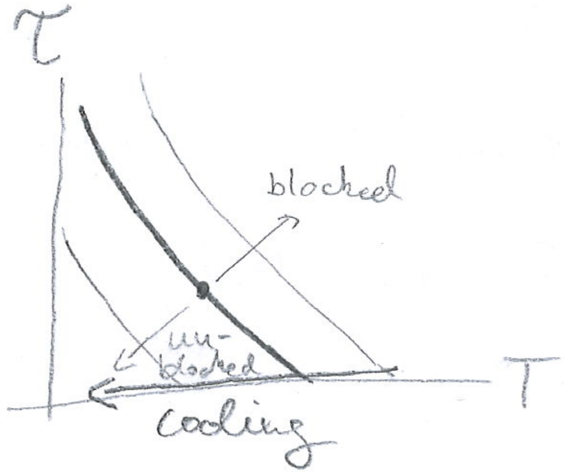
3) Cold (T = 20°C)



4) Reheating (T = 400°C)



5) Cooled sample (T = 20°C)

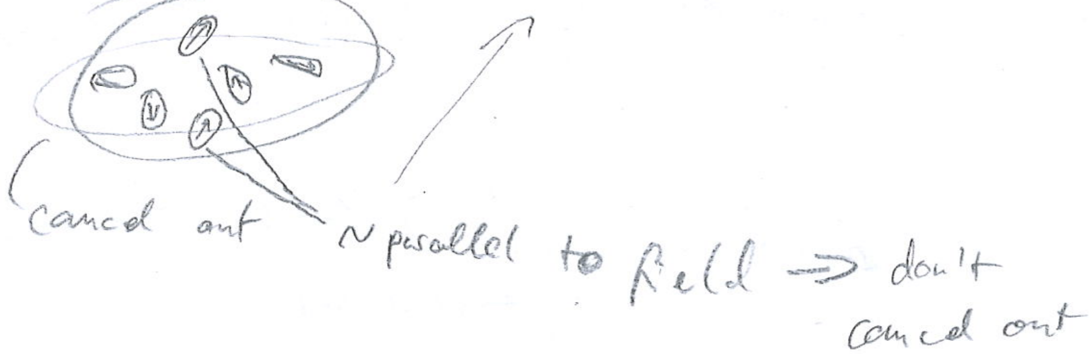


Question: How can a sample have 0 magnetisation?

Answer: M = 0 ⇒

Question Directions?

Answer:



"Stoner-Wohlfahrt" particles

PPT TRM part