

## Tempi caratteristici delle tecniche di caratterizzazione di materiali magnetici

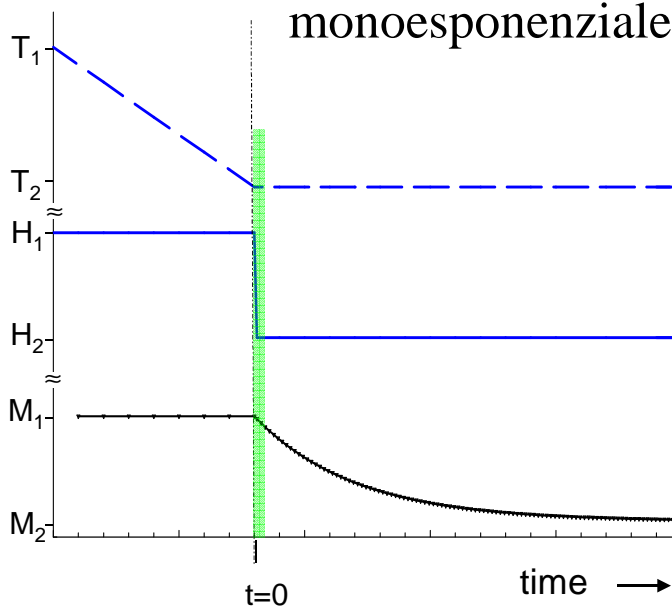
- Magnetometria ( $t > 100$  s)
- Suscettometria ac ( $10^{-5} - 1$  s)
- NMR ( $10^{-6} - 10^{-1}$  s)
- Muon spin resonance ( $10^{-6} - 10^{-3}$  s)
- Mossbauer ( $10^{-6}$  s)
- EPR ( $10^{-11}$  s)
- UV-Vis ( $10^{-13}$  s)
- Spettroscopia X-ray ( $10^{-15}$  s)

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### DECADIMENTO DELLA MAGNETIZZAZIONE

$$M(t) = M_2 + (M_1 - M_2) \exp(-t/\tau)$$

monoesponenziale



- Il tempo necessario a variare il campo deve essere  $\ll \tau$
- Il tempo di misura deve essere  $\gg \tau$  per determinare correttamente  $M_2$

$$M(t) = M_2 + (M_1 - M_2) \exp(-t/\tau)^{(1-\alpha)}$$

monoesponenziale stirato

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## ISTERESI TERMOMAGNETICA

Campo magnetico e temperatura vengono cambiati simultaneamente

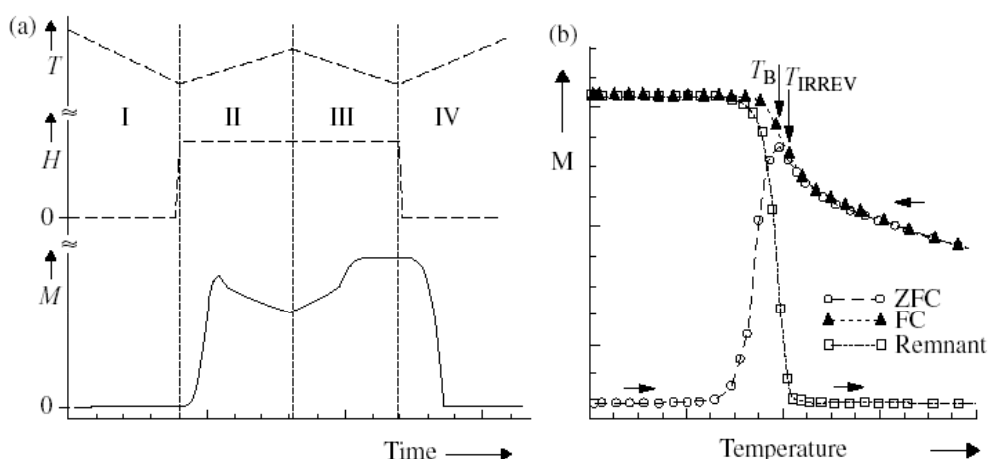
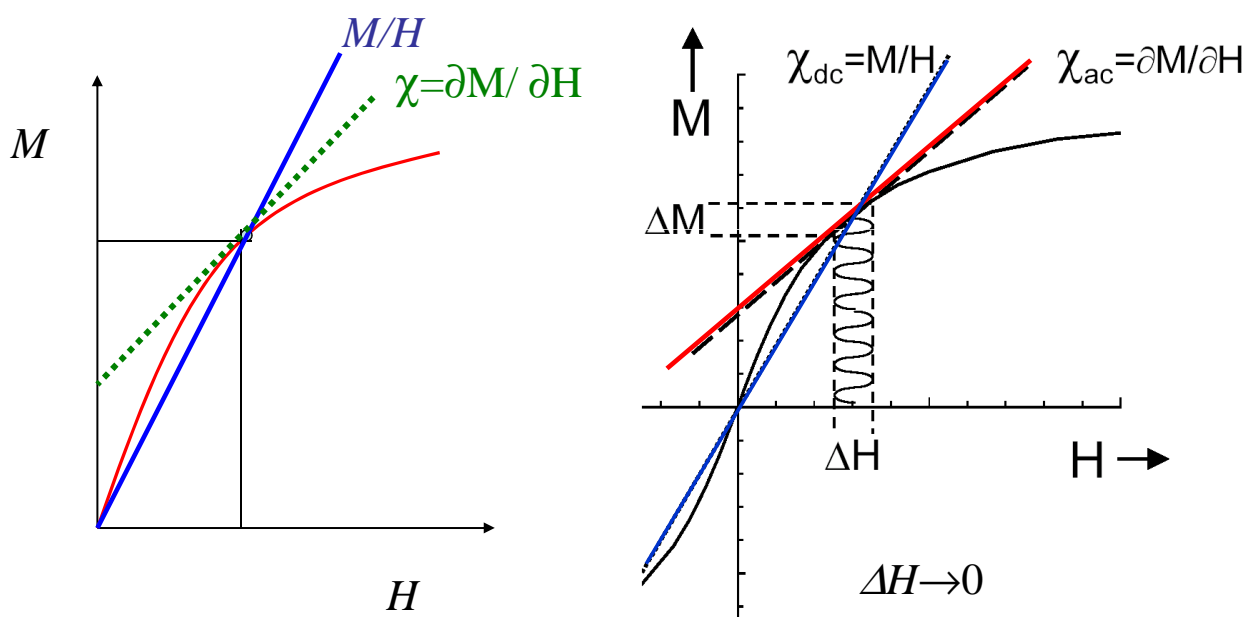


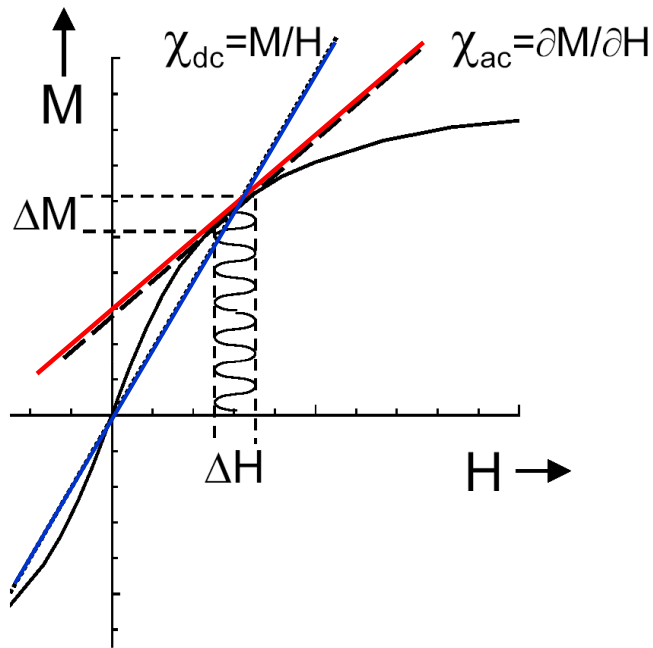
FIG. 3.7. (a) Schematic view of the procedure to measure the thermal irreversibility and thermo-remnant magnetization. The time dependence of the temperature (top), applied magnetic field (middle), and the measured magnetization (bottom) are reported. Step I corresponds to the cooling in zero field, step II to the measurement of ZFC magnetization, step III to FC magnetization, and step IV to the measurement of the thermo-remnant magnetization. (b) The magnetization measured in steps II, III, and IV is plotted as a function of the sample temperature.

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Il rapporto  $M/H$  viene spesso ed erroneamente chiamato suscettività statica



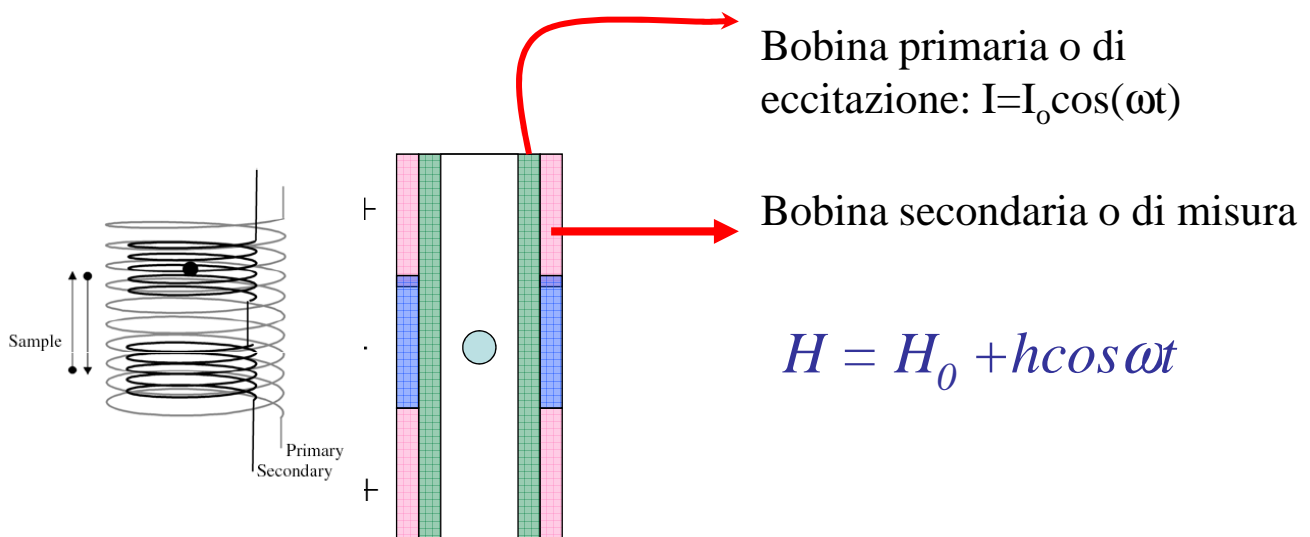
## I vantaggi della misura in campo magnetico oscillante



- Accesso alla vera suscettività (direttamente la derivata come in EPR)
- Sensibilità alta a basso campo
- Possibilità di variare la frequenza del campo magnetico oscillante (informazioni sulle proprietà dinamiche)

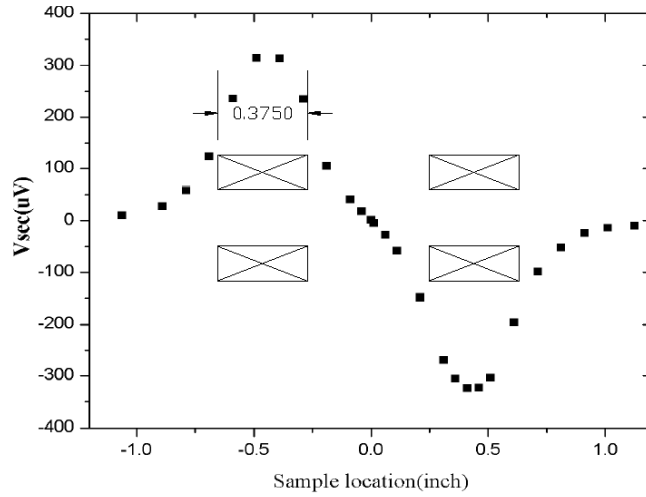
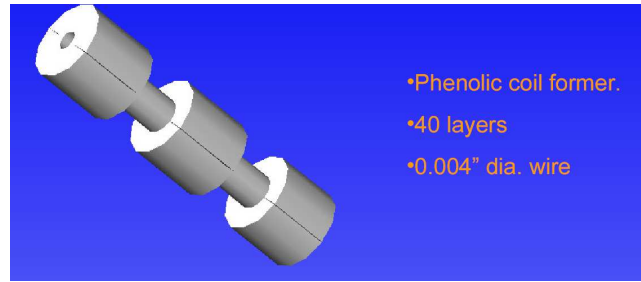
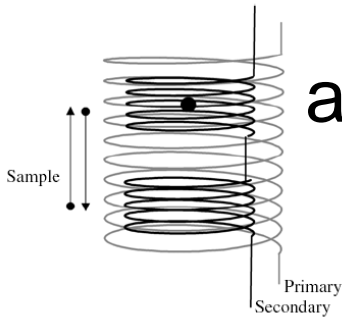
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## Suscettometro ac



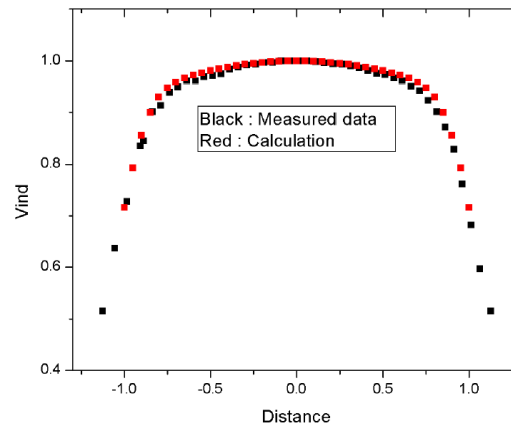
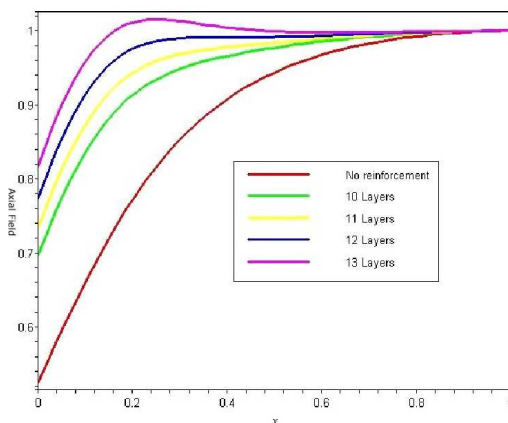
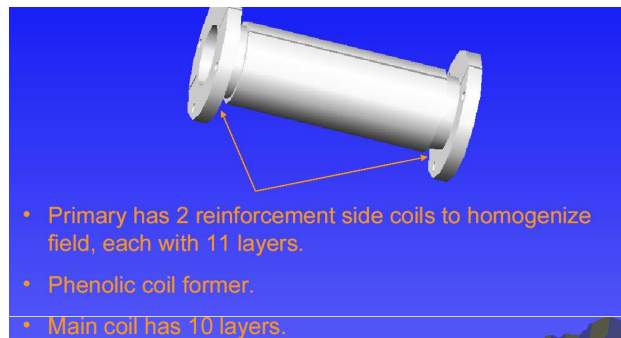
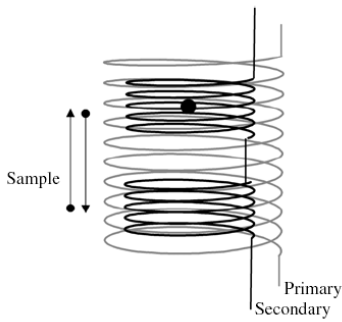
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# Suscettometro ac avvolgimento secondario



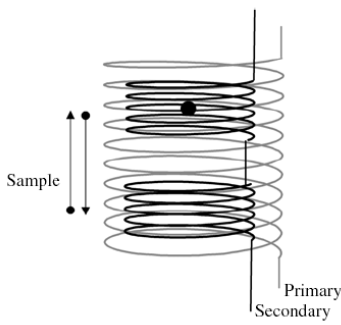
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# Suscettometro ac avvolgimento primario



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# Suscettometro ac



Bobina primaria o di  
eccitazione:  $I=I_0\cos(\omega t)$

$$H = H_0 + h\cos\omega t$$

$$e^{i\omega t} = \cos\omega t + i\sin\omega t$$

$$H = H_0 + he^{i\omega t}$$

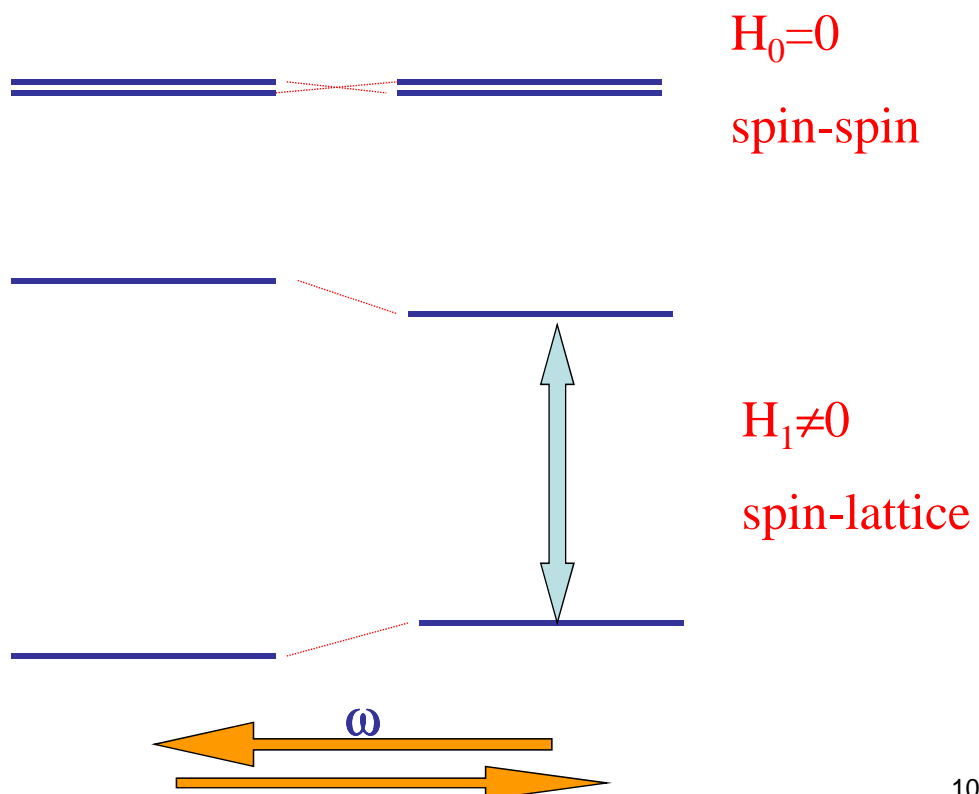
$$M(t) = M_0 + \text{Re}[(\chi' - i\chi'')he^{i\omega t}] = M_0 + (\chi'\cos\omega t + \chi''\sin\omega t)h$$

$$\chi(\omega) = \chi'(\omega) - i\chi''(\omega)$$

La parte immaginaria è legata alla  
Energia trasferita dal campo  
magnetico oscillante al sistema  
 $p > 0 \rightarrow \chi'' > 0$

$$p_{\text{av}} = \frac{1}{2}\mu_0\omega H_0^2 \chi''$$

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## Meccanismi di rilassamento spin-reticolo

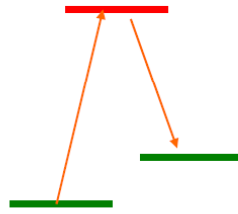
$$\frac{1}{\tau_1} = (Z_{\downarrow} + Z_{\uparrow})$$

diretto



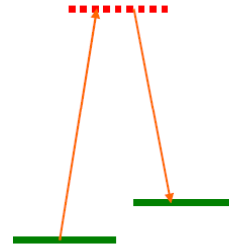
$$\frac{1}{\tau} \propto T$$

Orbach



$$\frac{1}{\tau} \propto \exp\left(-\frac{\Delta E}{k_B T}\right)$$

Raman

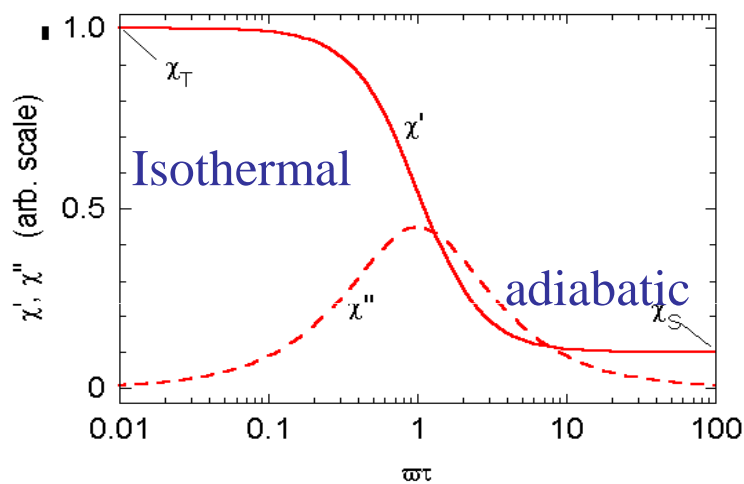


$$\frac{1}{\tau} \propto T^{\alpha}$$

$$5 < \alpha < 9 \quad 15$$

$$H = H_0 + h \cos \omega t$$

$$P_1/P_2 = \exp[-g\mu_B(H_0 + h \cos \omega t)/k_B T]$$



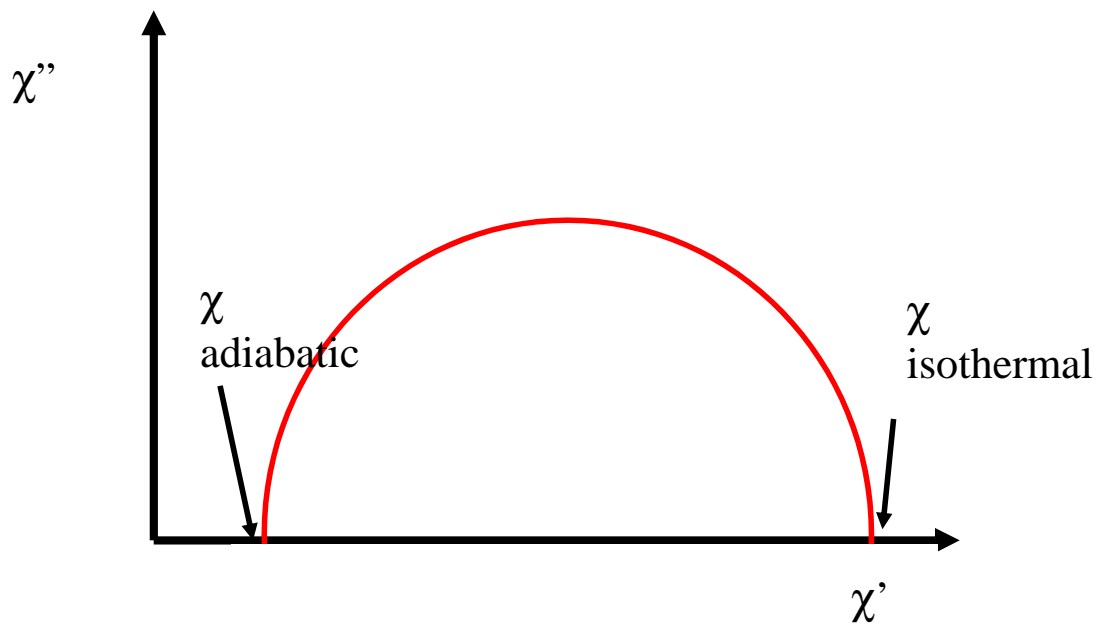
Casimir & Du Pré (1938)

$$\chi(\omega) = \chi_s + \frac{\chi_T - \chi_s}{1 + i\omega\tau}$$

$$\chi' = \frac{\chi_T - \chi_s}{1 + \omega^2 \tau^2} + \chi_s$$

$$\chi'' = \frac{(\chi_T - \chi_s)\omega\tau}{1 + (\omega\tau)^2}$$

Se il rilassamento è descritto da un solo tempo caratteristico il diagramma di Argand (l'equivalente del Cole –Cole plot per i dielettrici) è una semicirconferenza con centro sull'asse delle  $x$



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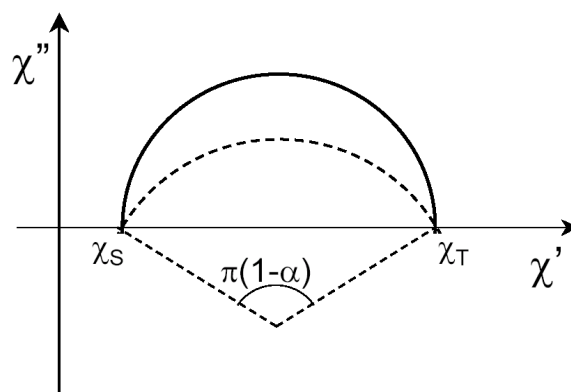
In presenza di una distribuzione di tempi di rilassamento (=esponenziale stirato nel decadimento di  $M$ )

$$\chi(\omega) = \chi_S + \frac{\chi_T - \chi_S}{1 + (i\omega\tau)^{1-\alpha}}$$

and

$$\chi'(\omega) = \chi_S + (\chi_T - \chi_S) \frac{1 + (\omega\tau)^{1-\alpha} \sin(\pi\alpha/2)}{1 + 2(\omega\tau)^{1-\alpha} \sin(\pi\alpha/2) + (\omega\tau)^{2-2\alpha}}$$

$$\chi''(\omega) = (\chi_T - \chi_S) \frac{(\omega\tau)^{1-\alpha} \cos(\pi\alpha/2)}{1 + 2(\omega\tau)^{1-\alpha} \sin(\pi\alpha/2) + (\omega\tau)^{2-2\alpha}}$$



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