Dilatometry

Materials from the 2007 presentation of

George Schmiedeshoff, Occidental College

were heavily used

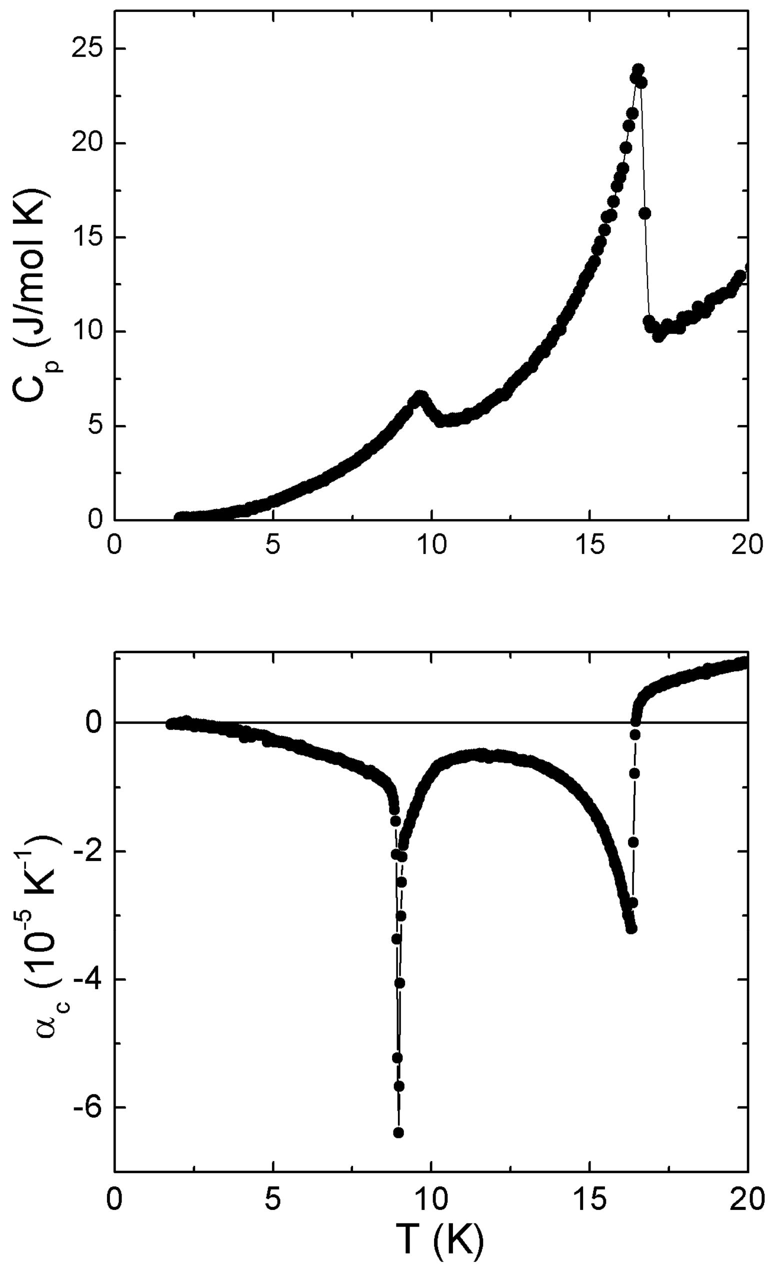
Dilation: ΔV (or ΔL)

Intensive Parameters:

- T: thermal expansion: $\beta = d\ln(V)/dT$
- H: magnetostriction: $\lambda = \Delta L(H)/L$
- P: compressibility: $\kappa = d\ln(V)/dP$
- E: electrostriction: $\xi = \Delta L(E)/L$
- *etc.*

A (very) Brief History

- **Heron** of Alexandria (0±100): Fire heats air, air expands, opening temple doors (first practical application…).
- **Galileo** (1600±7): Gas thermometer.
- **Fahrenheit** (1714): Mercury-in-glass thermometer.
- **Mie** (1903): First microscopic model.
- **Grüneisen** (1908): $\beta(T)/C(T) \sim$ constant.



$TbNi_2Ge_2$

(Ising Antiferromagnet)

after gms *et al.* AIP Conf. Proc. **850**, 1297 (2006). (LT24)

2^{nd} Order Phase Transition, Ehrenfest Relation(s):

$$\frac{dT_{N2}}{dp_c} = V_M T_{N2} \frac{\Delta\alpha_c}{\Delta C_p}$$

1^{st} Order Phase Transition, Clausius-Clapyeron Eq(s).:

$$\frac{dT_{N1}}{dp_c} = \frac{\Delta V}{\Delta S} \approx V_M \frac{\Delta(\frac{\Delta L}{L})}{\Delta S}$$

Paul Ehrenfest (1880-1933)

PhD from Vienna Technical University

1904 – married Tatyana Alexeyevna Afanasieva – Russian mathematician

1907-1912 – St. Petersburg, Russia (happiest days of his life)

1912-1933 - professor in Leiden

Depression…

Ehrenfest theorem

Ehrenfest paradox

Ehrenfest-Tolman effect

Classification of phase transitions

Ehrenfest time

Spinor

He was not merely the best teacher in our profession whom I have ever known; he was also passionately preoccupied with the development and destiny of men, especially his students. A. Einstein

Grüneisen Theory (one energy scale: U_o)

$$\Gamma \equiv -\frac{\partial \ln U_o}{\partial \ln V} = V_M \kappa(T) \frac{\beta(T)}{C_p(T)} = const.$$

$$U_o \propto V^{-\Gamma}$$

e.g.: If $U_o = E_F$ (ideal) then: $\Gamma_{IFG} = \frac{2}{3}$

Grüneisen Theory (multiple energy scales: U_i each with C_i and Γ_i)

$$\Gamma \equiv \frac{\sum_i C_i(T)\Gamma_i}{\sum_i C_i(T)} = \Gamma(T)$$

e.g.: phonon, electron, magnon, CEF, Kondo, RKKY, *etc.*

$$\Gamma_{eff} \equiv V_M \kappa(T) \frac{\beta(T)}{C_p(T)} = \Gamma_{eff}(T)$$

Examples: Simple metals: $\Gamma \sim 2$

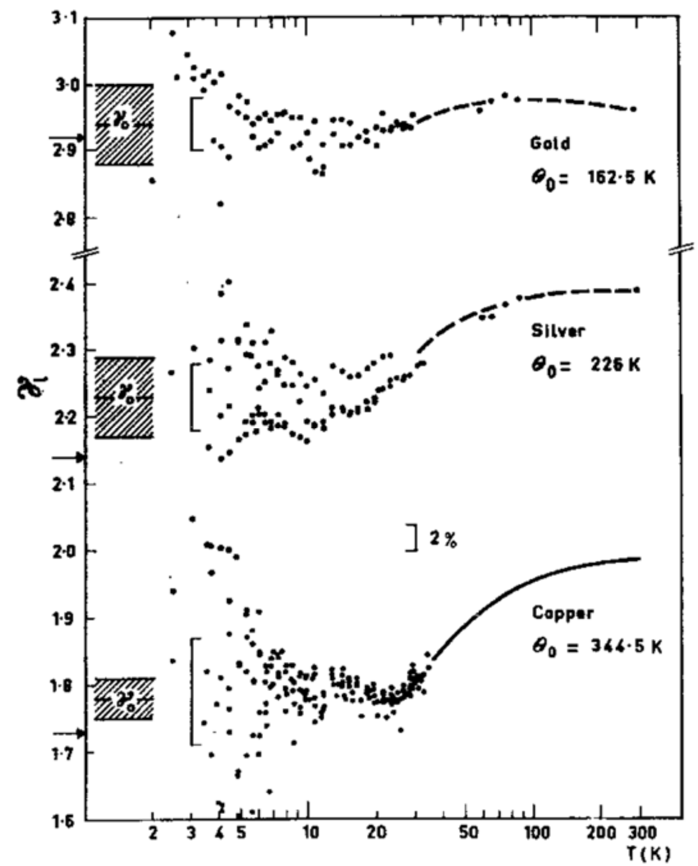
$$\Gamma_e = \frac{2}{3} + \frac{d\ln(m^*)}{d\ln(V)}$$

Example (Noble Metals):

After White & Collins, JLTP (1972).

Also: Barron, Collins & White, Adv. Phys. (1980).

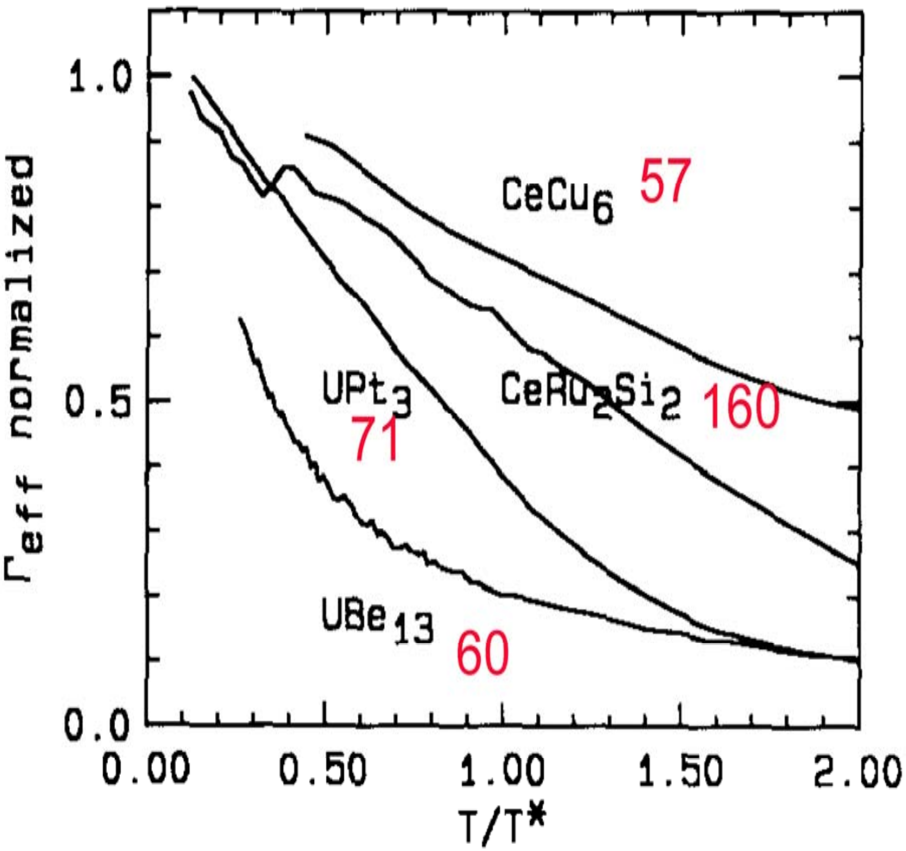
(Γ_{lattice} shown.)



Example (Heavy Fermions):

$\Gamma_{HF}(0)$

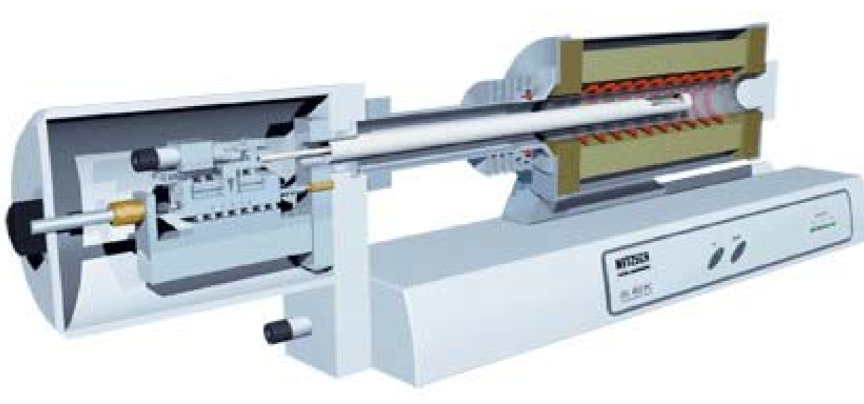
After deVisser *et al*. (1990)



Dilatometers

- Mechanical (pushrod *etc.)*
- Optical (interferometer *etc*.).
- Electrical (Inductive, Capacitive, Strain Gauges).
- Diffraction (X-ray, neutron).
- Others (absolute & differential).

NEITZSCH – DIL 402

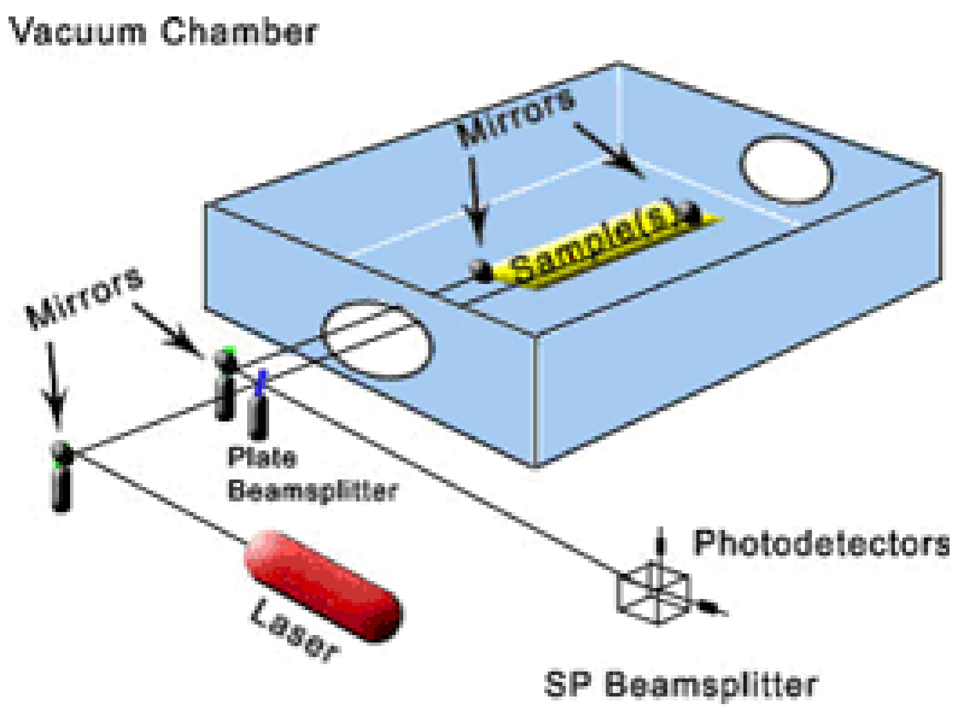


push-rod with inductive readout
(Ames Laboratory thermal analysis facility in Wilhelm Hall)

Technical Specifications

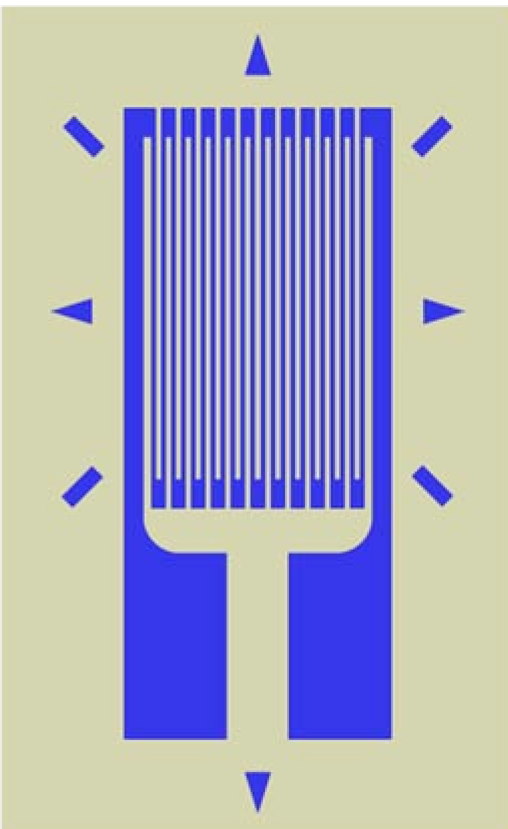
Furnaces (exchangeable):	RT … 1200°C, RT … 1600°C
Heating/Cooling rates:	0 … 50 K/min
Sample holders:	Fused Silica (max. 1100°C)
	Alumina (max. 1600°C)
	(user exchangeable)
Sample thermocouple:	type S (Pt/Pt10%Rh)
Measurement range:	500/5000 µm
Resolution:	up to 8 nm/digit
Sample diameter	≈1 … 12 mm
Sample length:	0 … 50 mm
Atmospheres:	oxid. (static, dynamic), inert
Electronics:	integrated TASC 414/5
PC-Interface:	USB

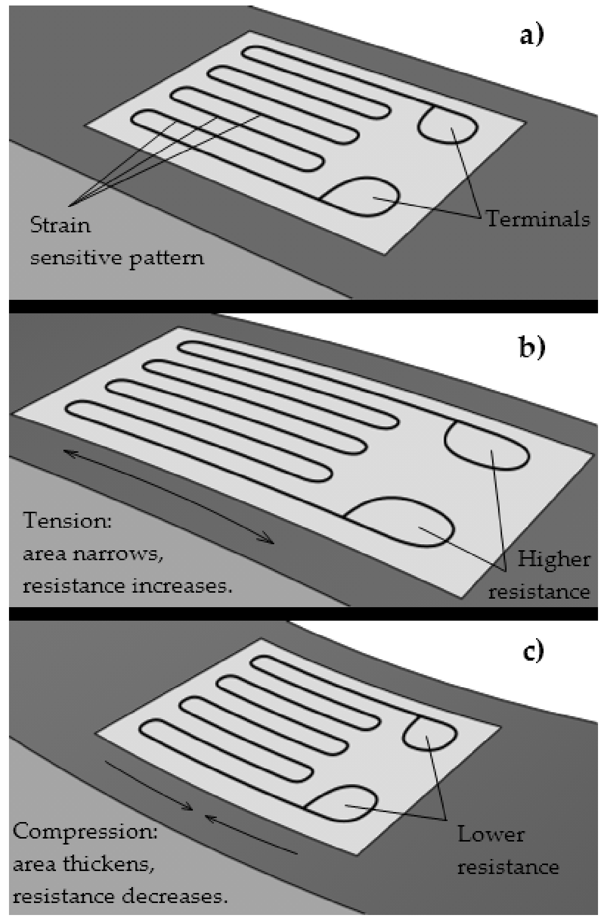
Optical dilatometer - interferometer



nanometer resolution, commercially available

Strain gauges





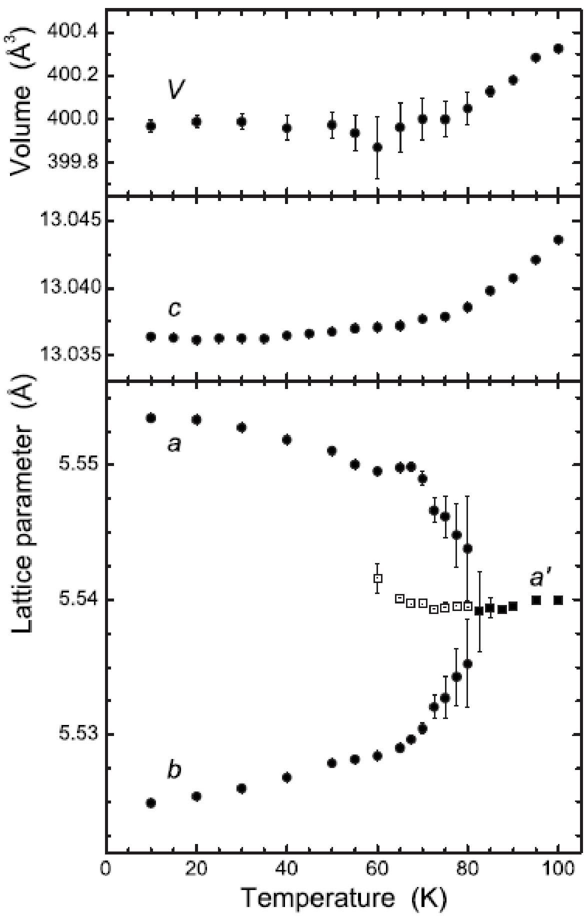
Gauge factor, GF = [ΔR/R]/[ΔL/L] is usually about 2 (for metal film gauges)

PHYSICAL REVIEW B 78, 014507 (2008)

Anisotropic thermodynamic and transport properties of single-crystalline $Ba_{1-x}K_xFe_2As_2$ (x=0 and 0.45)

N. Ni,[1,2] S. L. Bud'ko,[1,2] A. Kreyssig,[1,2] S. Nandi,[1,2] G. E. Rustan,[1,2] A. I. Goldman,[1,2] S. Gupta,[1,3] J. D. Corbett,[1,3] A. Kracher,[1] and P. C. Canfield[1,2]

XRD dilatometry

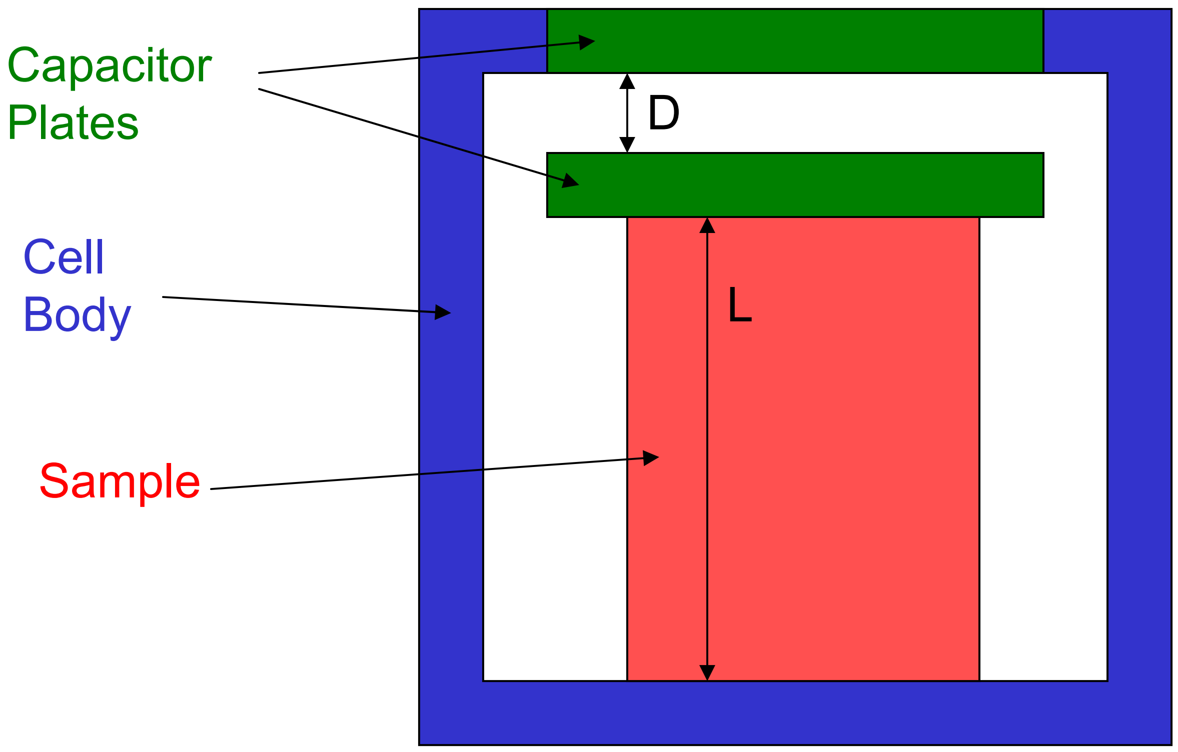


Less accurate

Tedious/expensive

VERY useful for structural phase transitions (gives structural information)

Capacitive Dilatometer (Cartoon)



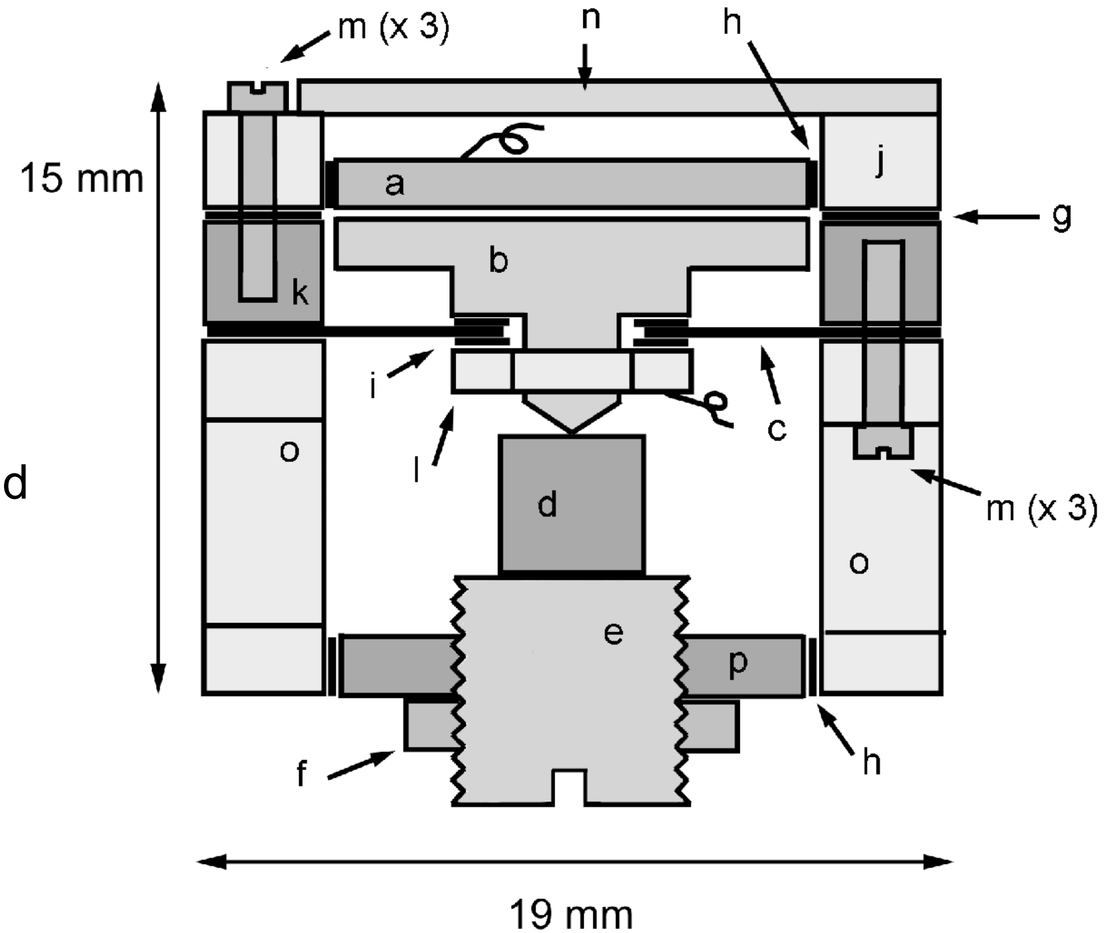
$$C = \varepsilon_o \frac{A}{D}$$

D3

Rev. Sci. Instrum. **77**, 123907 (2006)

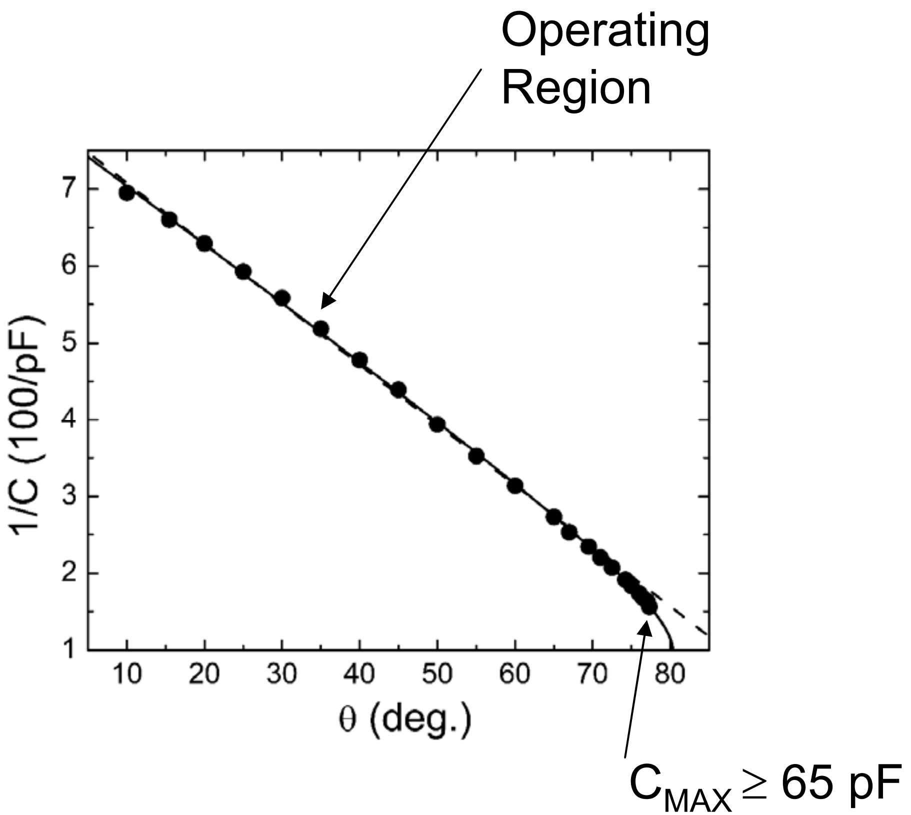
(cond-mat/0617396 has fewer typos…)

- Cell body: OHFC Cu.
- BeCu spring (c).
- Stycast 2850FT (h) and Kapton (i) insulation.
- Sample (d).



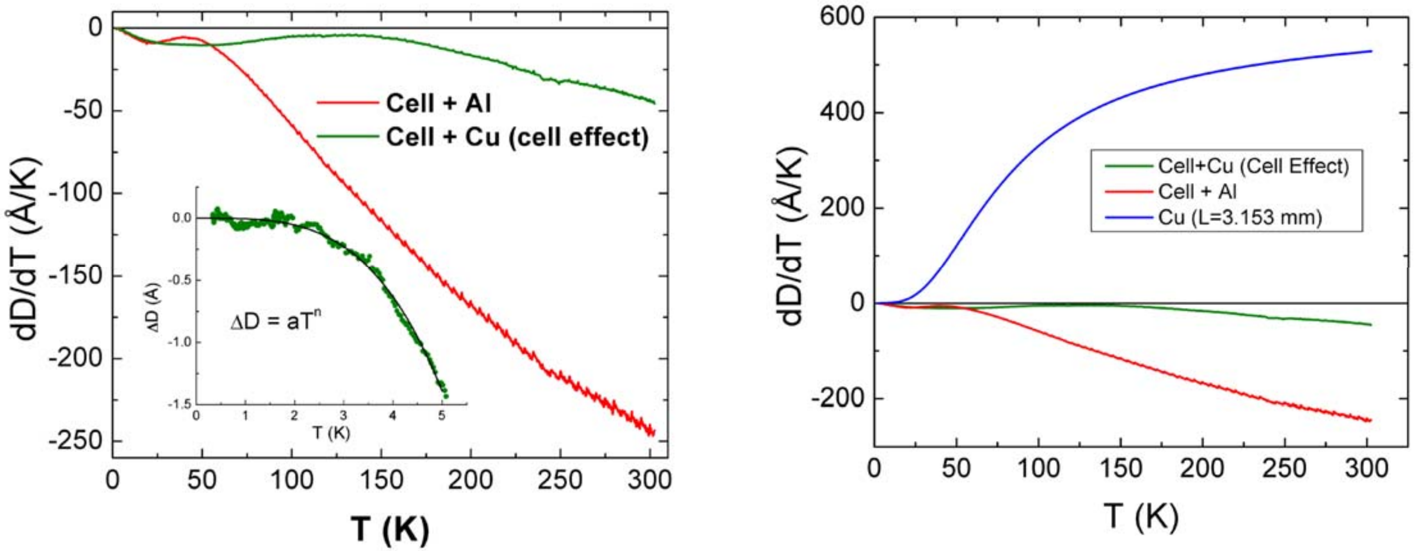
Calibration

- Use sample platform to push against lower capacitor plate.
- Rotate sample platform (θ), measure C.
- A_{eff} from slope (edge effects).
- $A_{eff} = A_o$ to about 1%?!
- "Ideal" capacitive geometry.
- Consistent with estimates.
- C_{MAX} >> C: no tilt correction.

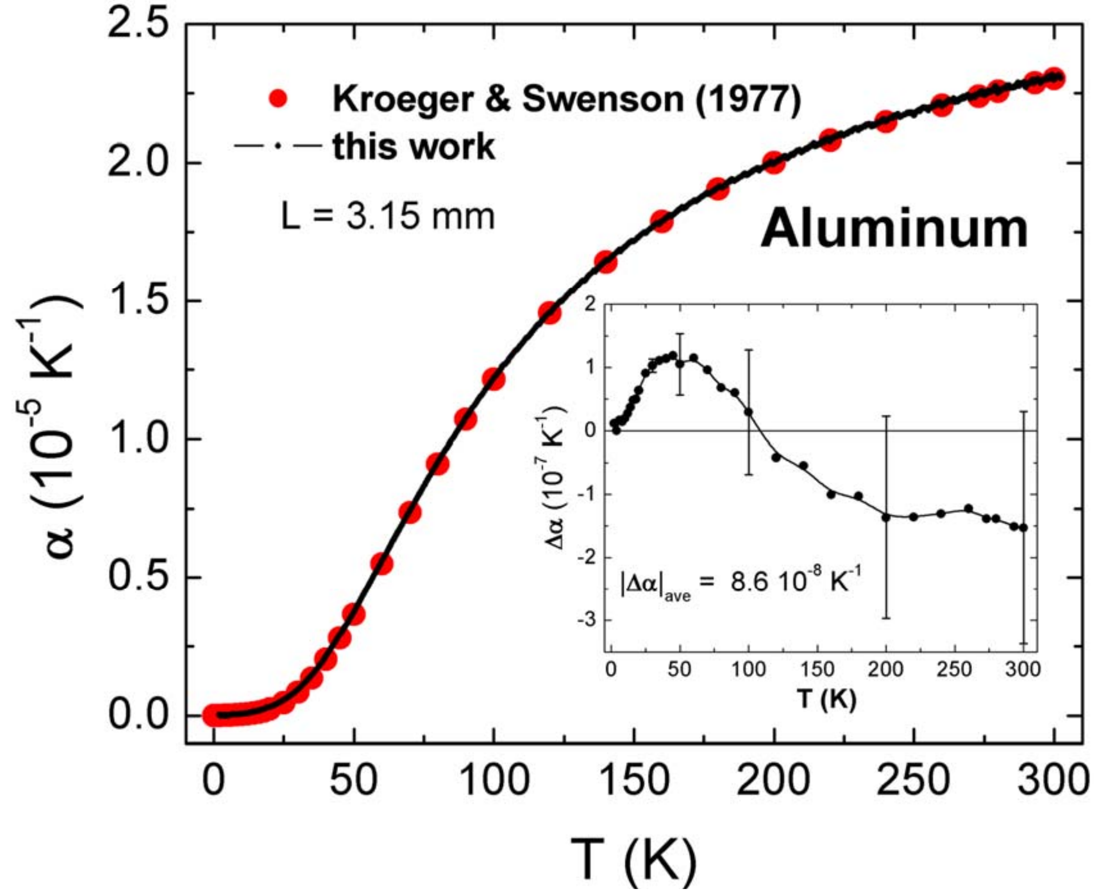


Cell Effect

$$\alpha_{Sample} = \frac{1}{L}\frac{dL}{dT}\bigg|_{Sample+Cell} - \frac{1}{L}\frac{dL}{dT}\bigg|_{Cell+Cu} + \alpha_{Cu}$$



<u>Much</u> smaller cell effect, above ~10K, using quartz (or sapphire?) instead of Cu for cell body. See, for example, Neumeier *et al.* (2005) and references therein.



Kroeger & Swenson (1977)
this work
L = 3.15 mm
Aluminum
α (10^-5 K^-1)
T (K)
Δα (10^-7 K^-1)
|Δα|ave = 8.6 10^-8 K^-1
T (K)

Tilt Correction

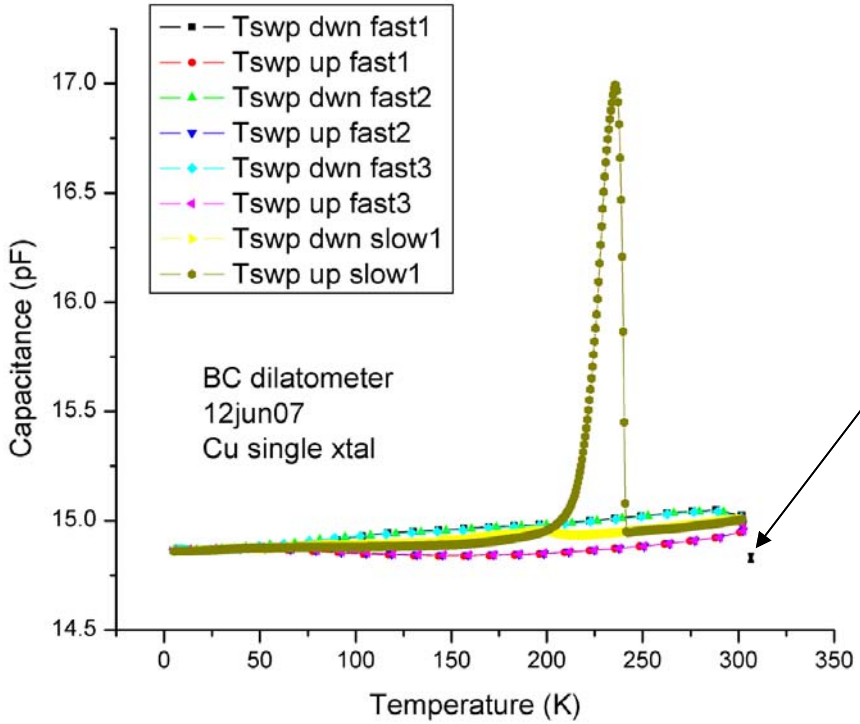
- If the capacitor plates are truly parallel then $C \to \infty$ as $D \to 0$.
- More realistically, if there is an angular misalignment, one can show that $C \to C_{MAX}$ as $D \to D_{SHORT}$ (plates touch) and that

$$D = \frac{\varepsilon_o A}{C}\left[1 + \left(\frac{C}{C_{MAX}}\right)^2\right]$$

Pott & Schefzyk (1988).

- For our design, C_{MAX} = 100 pF corresponds to an angular misalignment of about 0.1^{o}.
- Tilt is not always bad: enhanced sensitivity is exploited in the design of Rotter *et al.* (1998).

Kapton Bad (thanks to A. deVisser and Cy Opeil)



- Replace Kapton washers with alumina.
- New cell effect scale.
- Investigating sapphire washers.

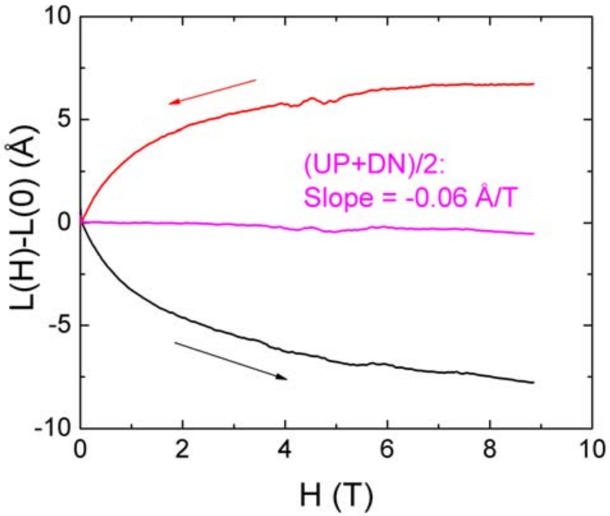
Torque Bad

- The dilatometer is sensitive to magnetic torque on the sample (induced moments, permanent moments, shape effects…).
- Manifests as irreproducible magnetostriction (for example).
- Best solution (so far…): glue sample to platform.
- Duco cement, GE varnish, N-grease…
- Low temperature only. Glue contributes above about 20 K.

Hysteresis ~Bad

- Cell is very sensitive to thermal gradients: thermal hysteresis. But slope is unaffected if T changes slowly.

- Magnetic torque on induced eddy-currents: magnetic hysteresis. But symmetric hysteresis averages to “zero”:

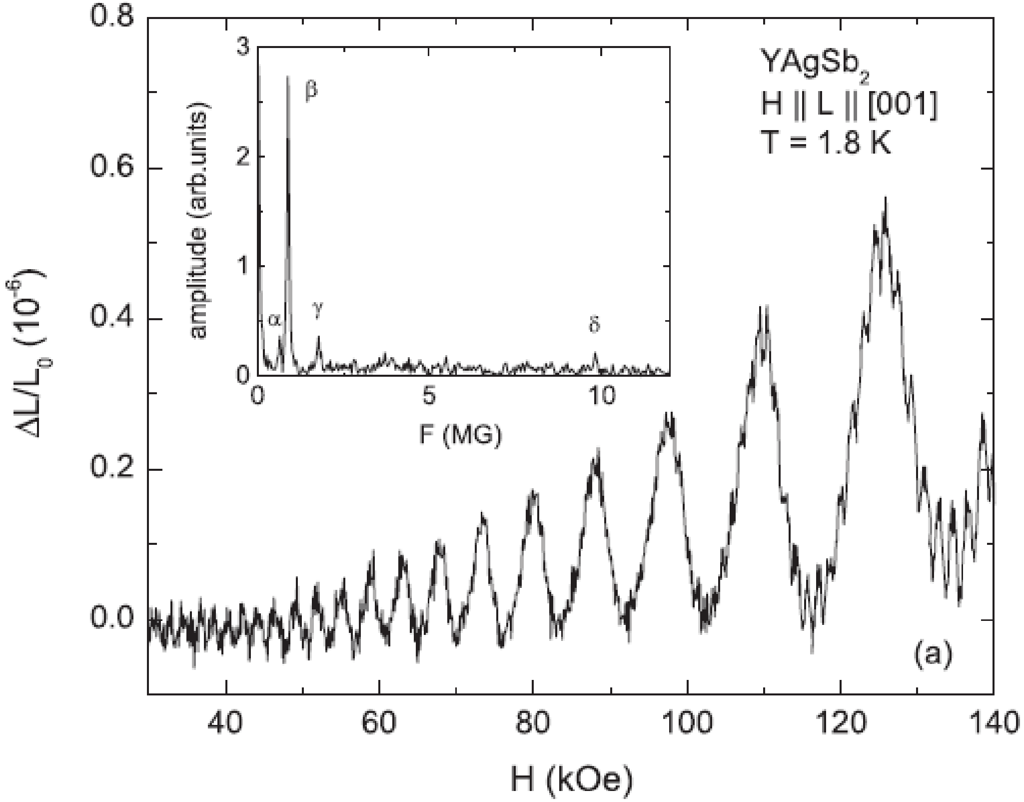


IOP PUBLISHING JOURNAL OF PHYSICS: CONDENSED MATTER
J. Phys.: Condens. Matter 20 (2008) 115210 (10pp) doi:10.1088/0953-8984/20/11/115210

Thermal expansion and magnetostriction of pure and doped $RAgSb_2$ (R = Y, Sm, La) single crystals

S L Bud'ko[1], S A Law[1,4], P C Canfield[1], G D Samolyuk[1], M S Torikachvili[2] and G M Schmiedeshoff[3]

Quantum Oscillations



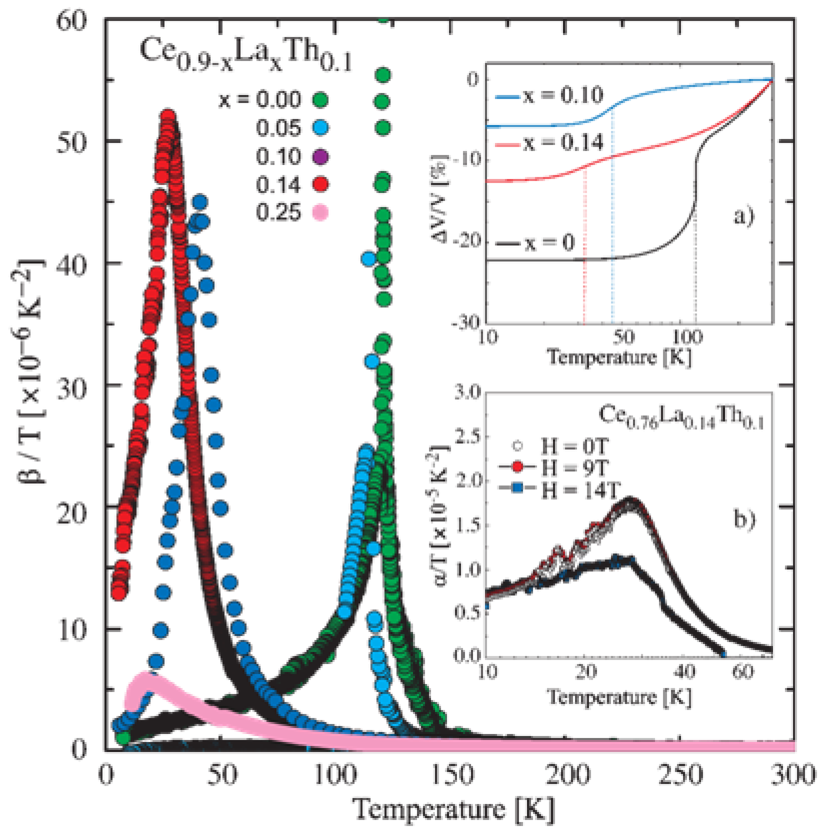
$$\epsilon_i = -MH\frac{\partial \ln S_m}{\partial \sigma_i}$$

Can estimate uniaxial pressure derivatives of the extremal FS cross-sections

PRL **97,** 235701 (2006) PHYSICAL REVIEW LETTERS week ending 8 DECEMBER 2006

Tricritical Phenomena at the $\gamma \rightarrow \alpha$ Transition in $Ce_{0.9-x}La_xTh_{0.1}$ Alloys

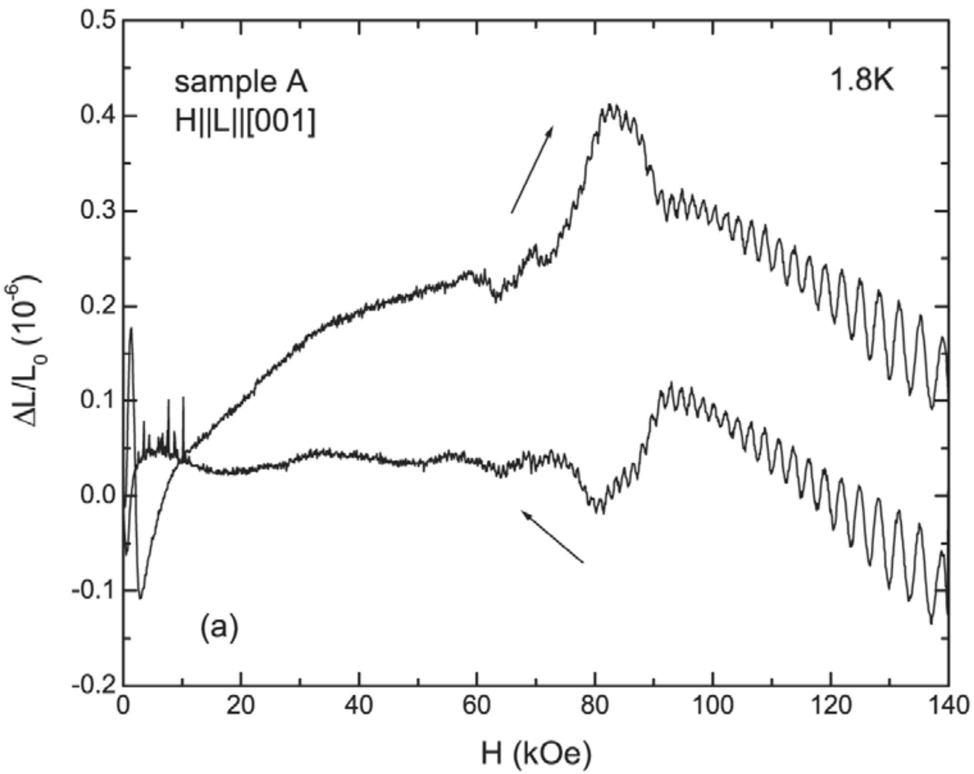
J. C. Lashley,[1] A. C. Lawson,[1] J. C. Cooley,[1] B. Mihaila,[1] C. P. Opeil,[1] L. Pham,[1] W. L. Hults,[1] J. L. Smith,[1]
G. M. Schmiedeshoff,[2] F. R. Drymiotis,[3] G. Chapline,[4] S. Basu,[5] and P. S. Riseborough[5]



INSTITUTE OF PHYSICS PUBLISHING JOURNAL OF PHYSICS: CONDENSED MATTER
J. Phys.: Condens. Matter **18** (2006) 8353–8365 doi:10.1088/0953-8984/18/35/020

Anisotropic thermal expansion and magnetostriction of YNi_2B_2C single crystals

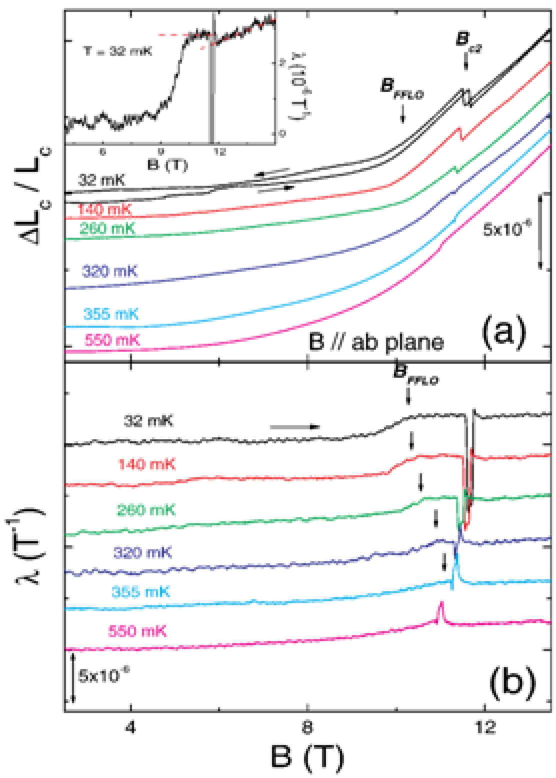
S L Bud'ko[1], G M Schmiedeshoff[2], G Lapertot[1,3] and P C Canfield[1]

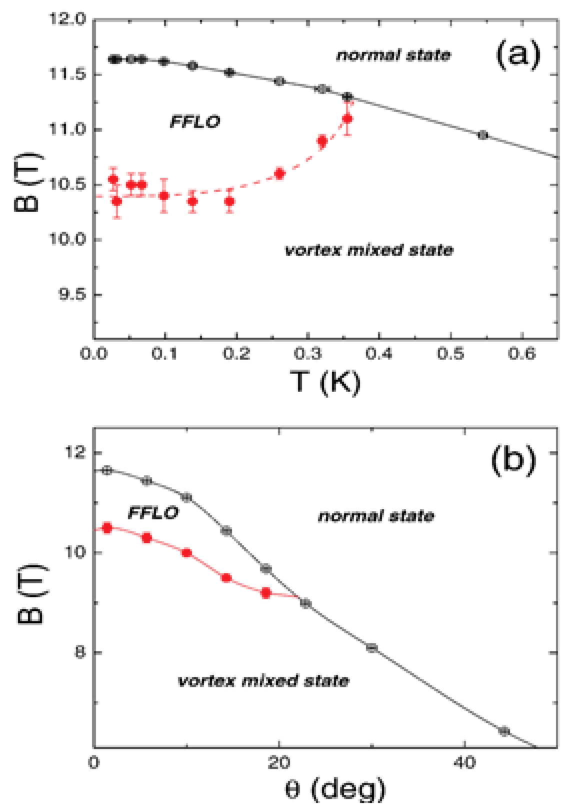


AMES LABORATORY

Magnetic-Field-Induced Lattice Anomaly inside the Superconducting State of $CeCoIn_5$: Anisotropic Evidence of the Possible Fulde-Ferrell-Larkin-Ovchinnikov State

V. F. Correa,[1,*] T. P. Murphy,[1] C. Martin,[1] K. M. Purcell,[1,2] E. C. Palm,[1] G. M. Schmiedeshoff,[3]
J. C. Cooley,[4] and S. W. Tozer[1]





Extreme Conditions Group

The Good & The Bad

- Small (scale up or down).
- Open architecture.
- Rotate *in-situ* (NHMFL/TLH).
- Vacuum, gas, or liquid (magnetostriction only?).
- Sub-angstrom precision.

- Cell effect ($T \geq 2K$).
- Magnetic torque effects.
- Thermal and magnetic hysteresis.
- Thermal contact to sample in vacuum ($T \leq 100mK$?).

Recommended:

- Book: *Heat Capacity and Thermal Expansion at Low Temperatures*, Barron & White, 1999.
- Collection of Review Articles: *Thermal Expansion of Solids*, v.I-4 of Cindas Data Series on Material Properties, ed. by C.Y. Ho, 1998.
- Book (broad range of data on technical materials *etc.*): *Experimental Techniques for Low Temperature Measurements*, Ekin, 2006.
- Book: *Magnetostriction: Theory and Applications of Magnetoelasticity*, Etienne du Trémolet de Lacheisserie, 1993.
- Book: *Thermal Expansion*, Yates, 1972.
- Review Article: Barron, Collins, and White; Adv. Phys. **29**, 609 (1980).
- Review Article: Chandrasekhar & Fawcett; Adv. Phys. **20**, 775 (1971).
- …and references therein.