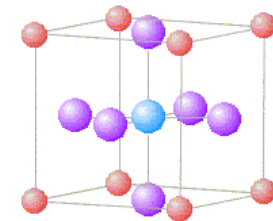
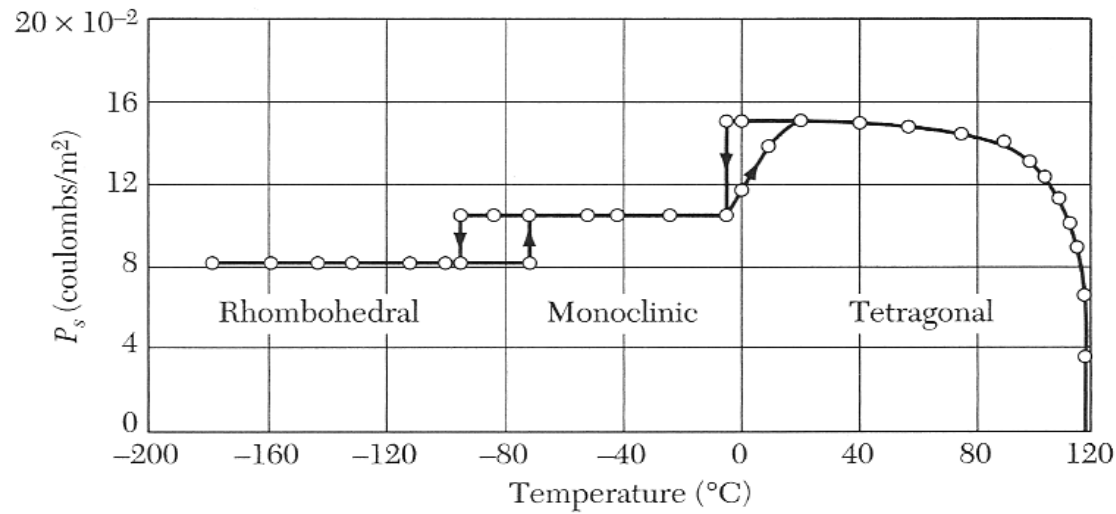
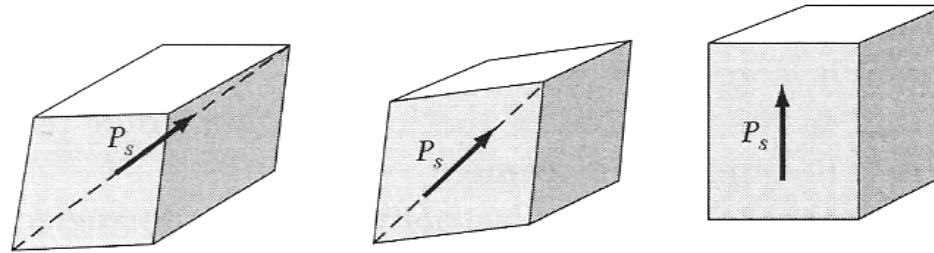


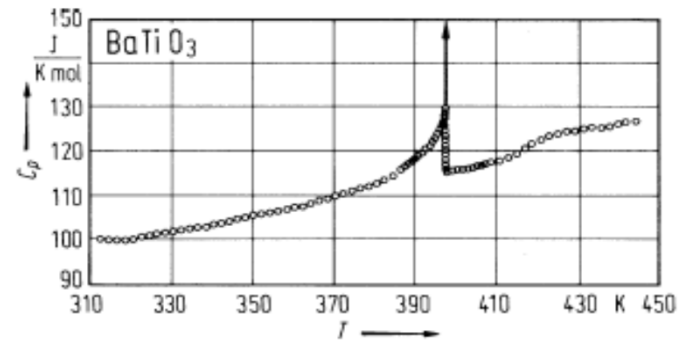
Ferroelectricity and Piezoelectricity

BaTiO₃



cubic (contains i = >
no spontaneous P)

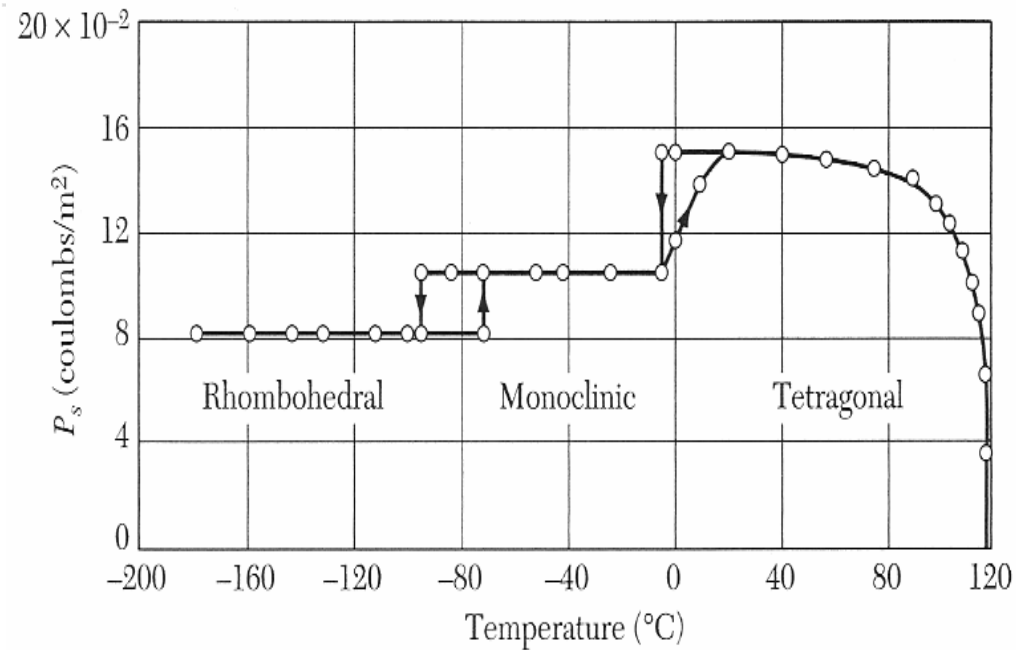
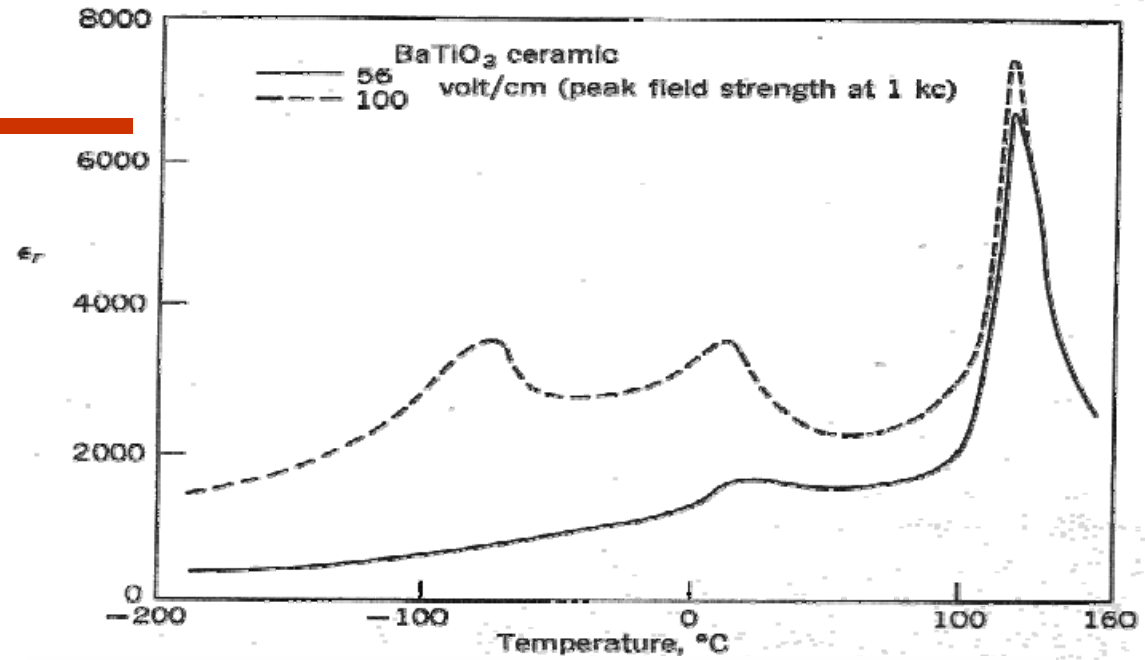
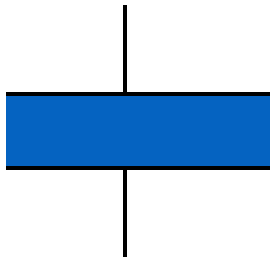
Can be used to make
nonvolatile memory



BaTiO₃

$$\epsilon_r = \chi + 1$$

Can be used to make
ultracapacitors

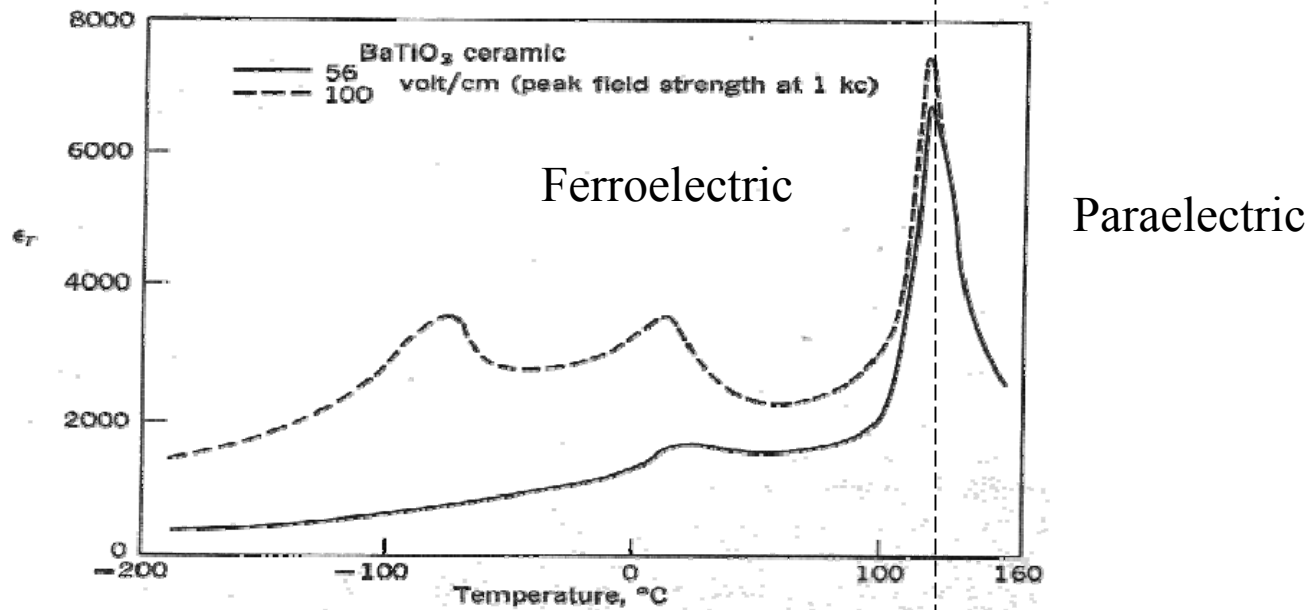


Paraelectric state

Above T_c , BaTiO₃ is paraelectric. The susceptibility (and dielectric constant) diverge like a Curie-Weiss law.

$$\chi \propto \frac{1}{T - T_c} \quad \epsilon = (1 + \chi) \epsilon_0$$

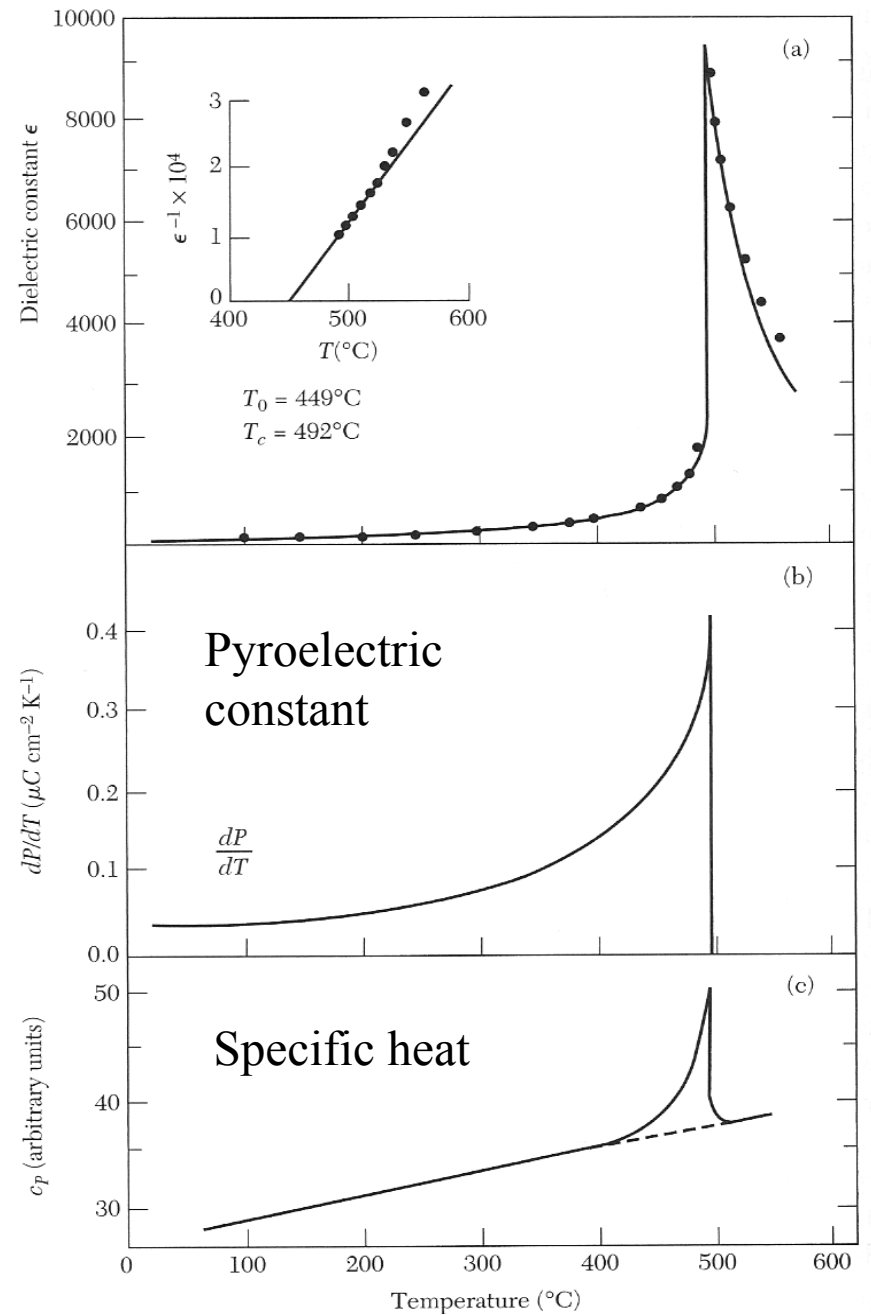
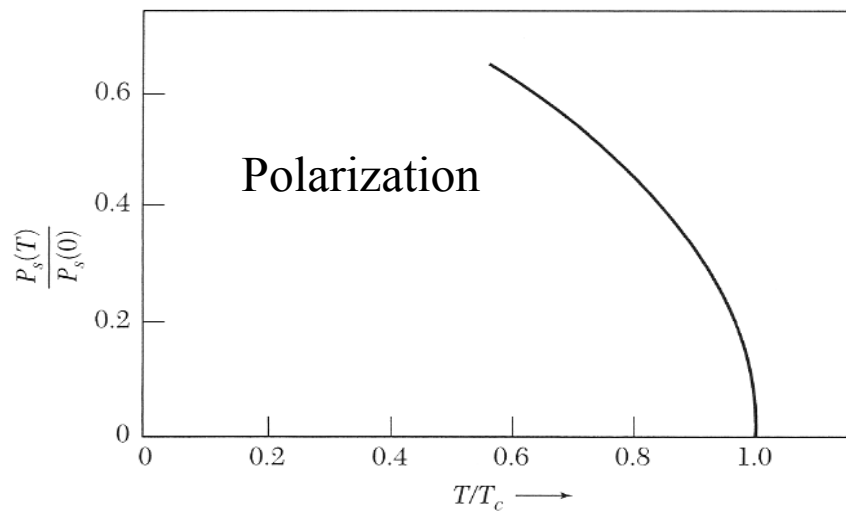
This causes a big peak in the dielectric constant at T_c .



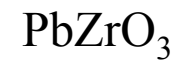
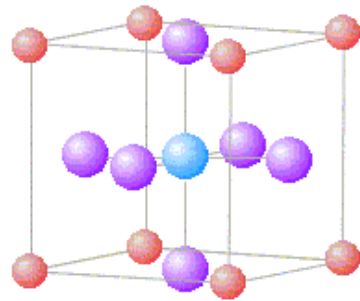
PbTiO₃

Dielectric constant

$$\epsilon \propto \frac{1}{T - T_c}$$



Antiferroelectricity

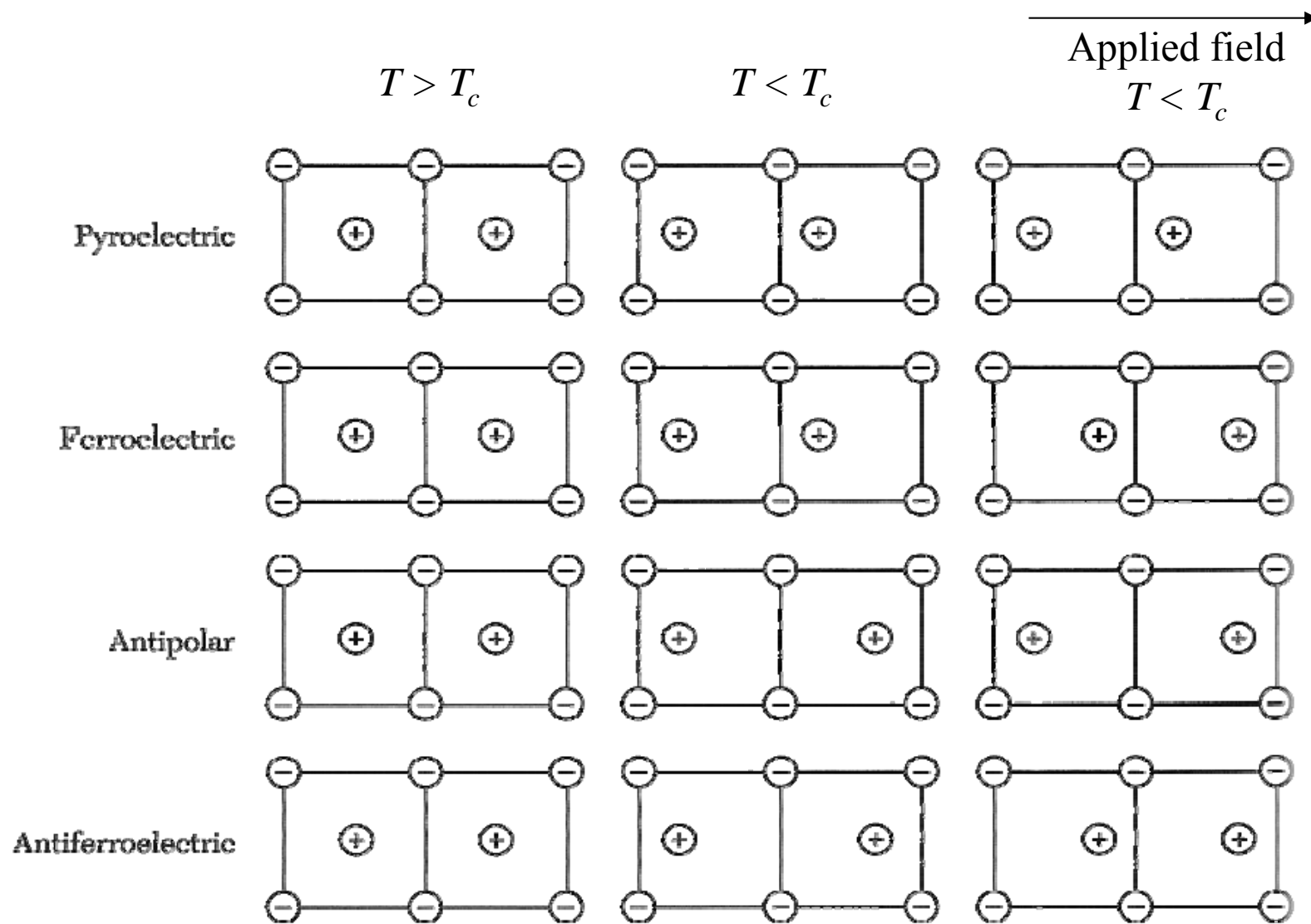


Polarization aligns antiparallel.

Associated with a structural phase transition.

Large susceptibility and dielectric constant near the transition.

Phase transition is observed in the specific heat, x-ray diffraction.



Piezoelectricity

Many piezoelectric materials are ferroelectric.

Electric field couples to polarization, polarization couples to structure.

lead zirconate titanate ($\text{Pb}[\text{Zr}_x\text{Ti}_{1-x}]\text{O}_3$ $0 < x < 1$)

—more commonly known as PZT

barium titanate (BaTiO_3) $T_c = 408 \text{ K}$

lead titanate (PbTiO_3) $T_c = 765 \text{ K}$

potassium niobate (KNbO_3) $T_c = 708 \text{ K}$

lithium niobate (LiNbO_3) $T_c = 1480 \text{ K}$

lithium tantalate (LiTaO_3) $T_c = 938 \text{ K}$

quartz (SiO_2), GaAs, GaN

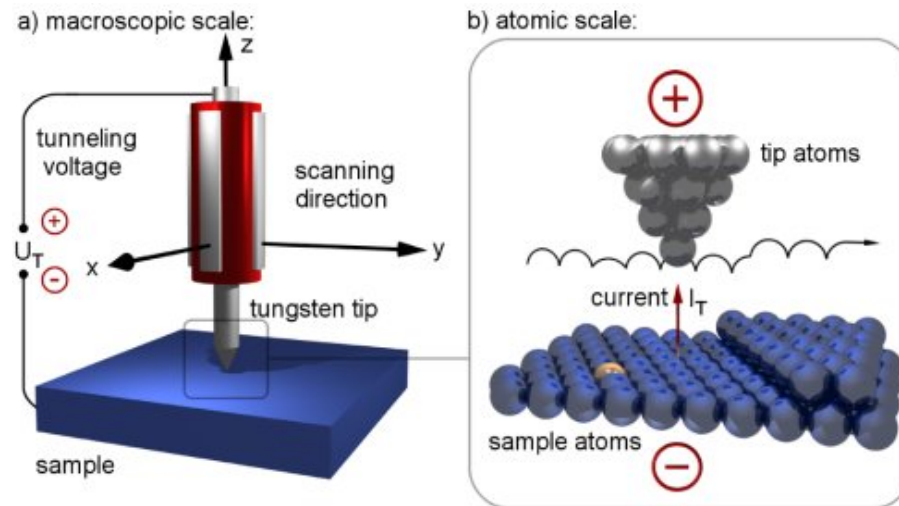
Gallium Orthophosphate (GaPO_4) $T_c = 970 \text{ K}$

Third rank tensor, No inversion symmetry

Piezoelectric crystal classes: 1, 2, m, 222, mm2, 4, -4, 422, 4mm, -42m, 3, 32, 3m, 6, -6, 622, 6mm, -62m, 23, -43m

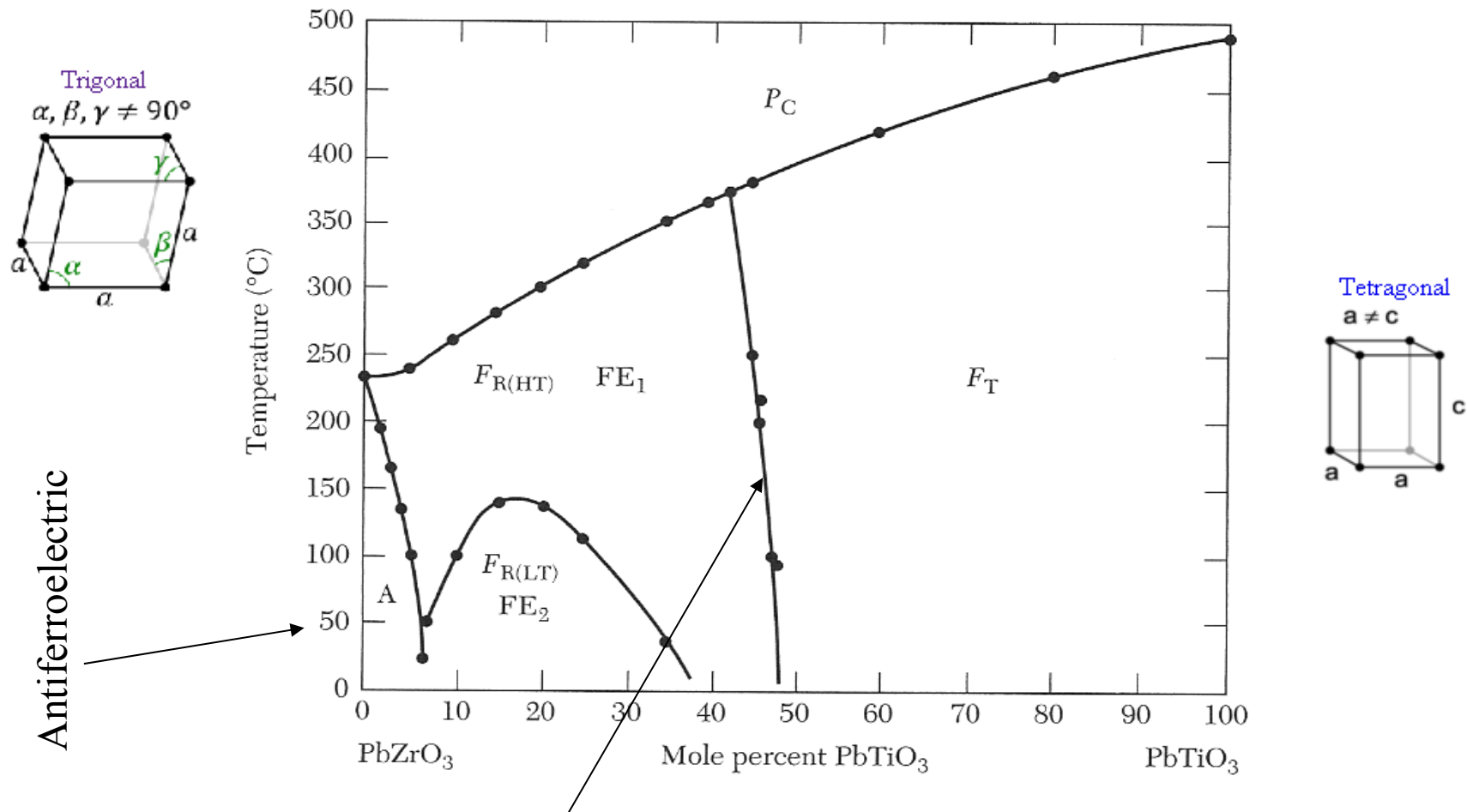
Piezoelectricity

When you apply a voltage across certain crystals, they get longer.



AFM's, STM's
Quartz crystal oscillators
Surface acoustic wave generators
Pressure sensors - Epcos
Fuel injectors - Bosch
Inkjet printers

PZT ($\text{Pb}[\text{Zr}_x\text{Ti}_{1-x}]\text{O}_3$ $0 < x < 1$)



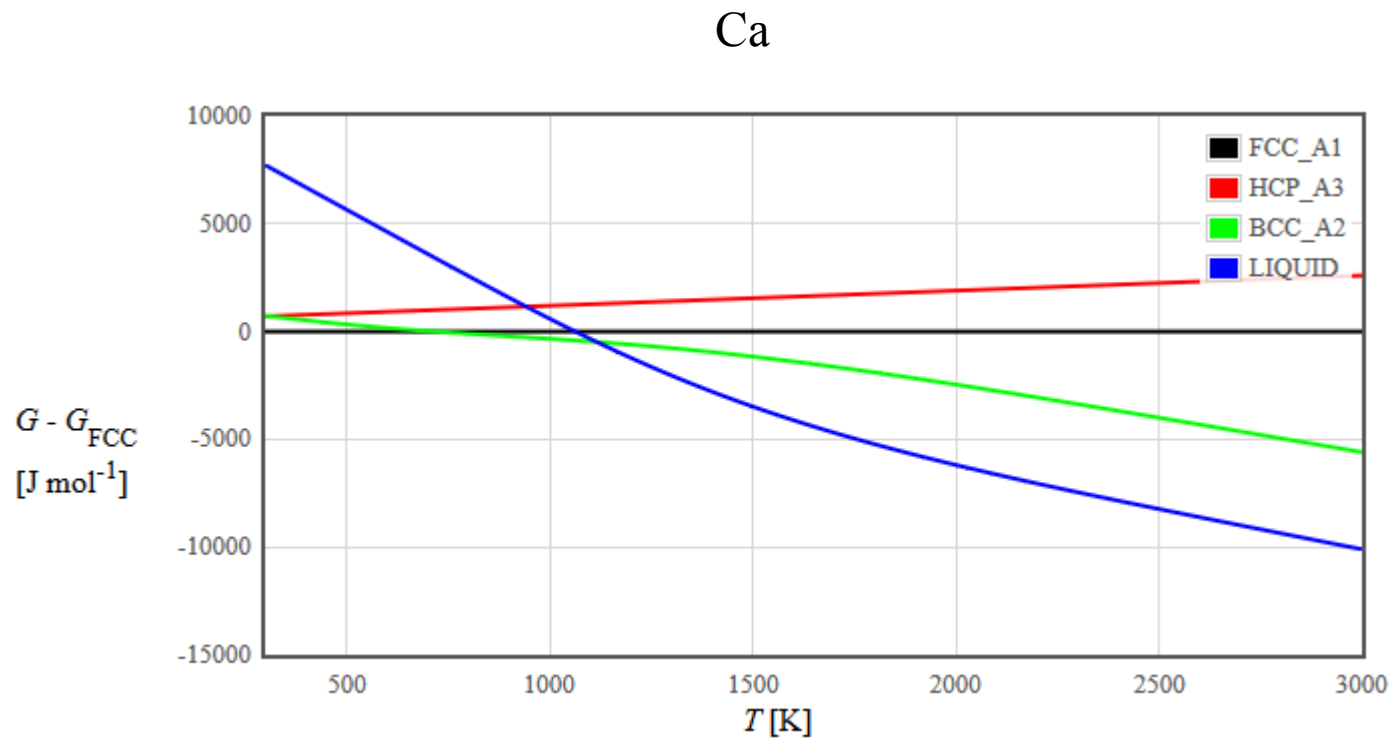
Large piezoelectric response near the rhombohedral-tetragonal transition.
Electric field induces a structural phase transition.

Nitinol

The part of the metal that is under compression goes into the more compact phase.

Phase transitions

Calculate the free energy of the electrons and phonons of each phase.
See which phase has the lowest energy.

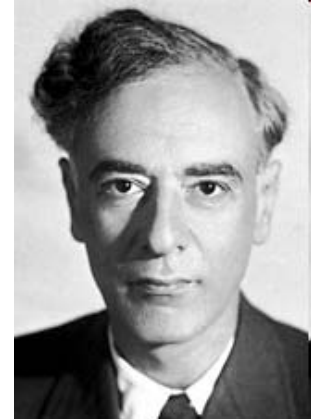


Landau theory of phase transitions

A phase transition is associated with a broken symmetry.

magnetism
cubic - tetragonal
water - ice
ferroelectric
superconductivity

direction of magnetization
different point group
translational symmetry
direction of polarization
gauge symmetry



Lev Landau