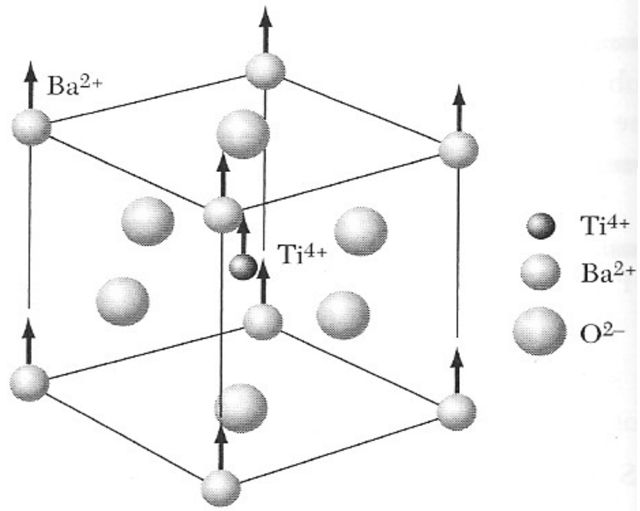
Ferroelectricity

ABX_3

Perovskites

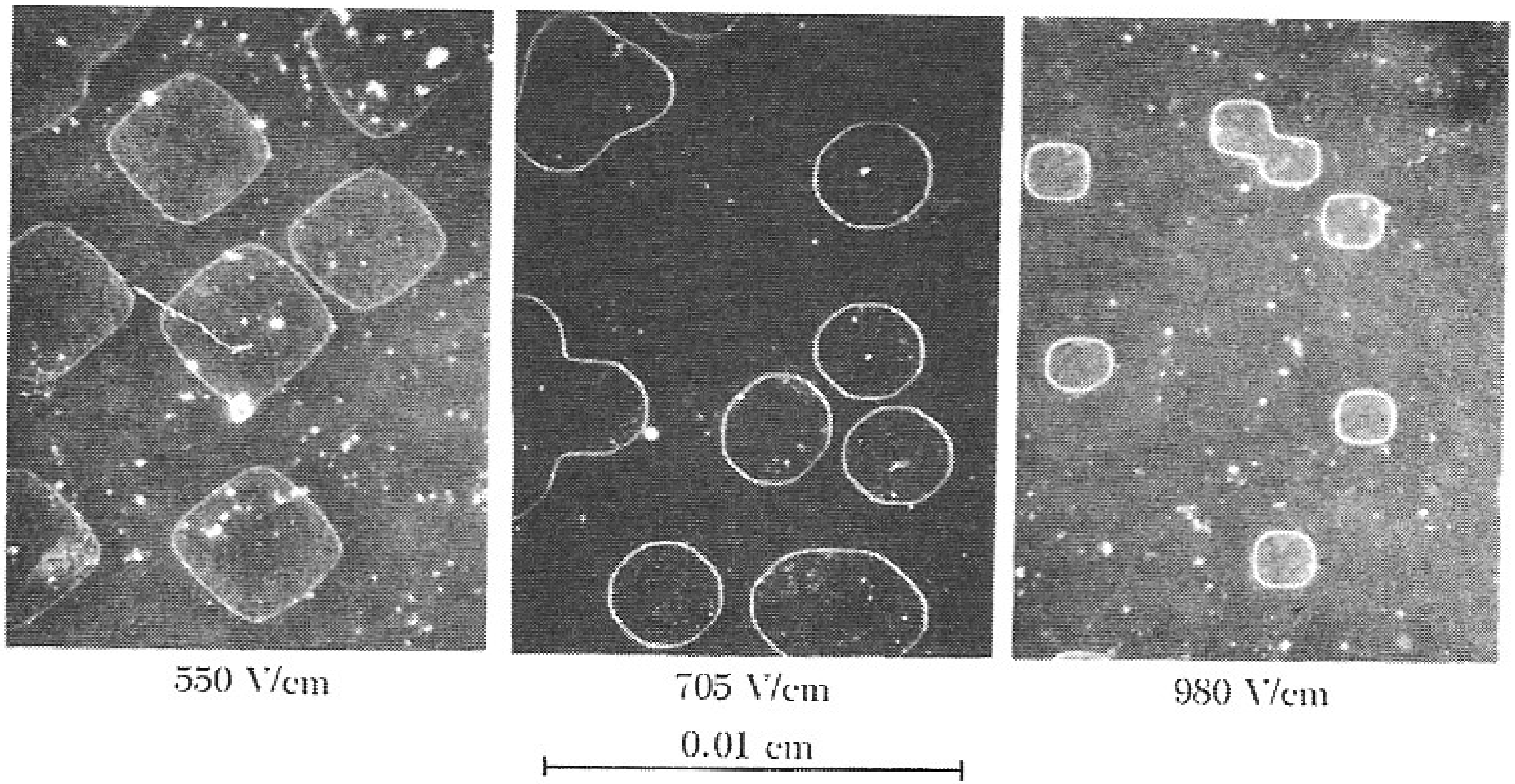


Spontaneous polarization
Analogous to ferromagnetism
Structural phase transition
T_c is transition temperature

Electric field inside the material,
is not conducting

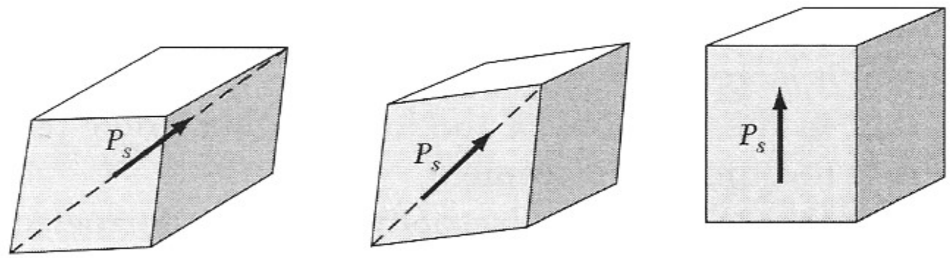
		T_c, in K	P_s, in $\mu C\ cm^{-2}$, at T K	
KDP type	KH_2PO_4	123	4.75	[96]
	KD_2PO_4	213	4.83	[180]
	RbH_2PO_4	147	5.6	[90]
	KH_2AsO_4	97	5.0	[78]
	GeTe	670	—	—
TGS type	Tri-glycine sulfate	322	2.8	[29]
	Tri-glycine selenate	295	3.2	[283]
Perovskites	$BaTiO_3$	408	26.0	[296]
	$KNbO_3$	708	30.0	[523]
	$PbTiO_3$	765	>50	[296]
	$LiTaO_3$	938	50	
	$LiNbO_3$	1480	71	[296]

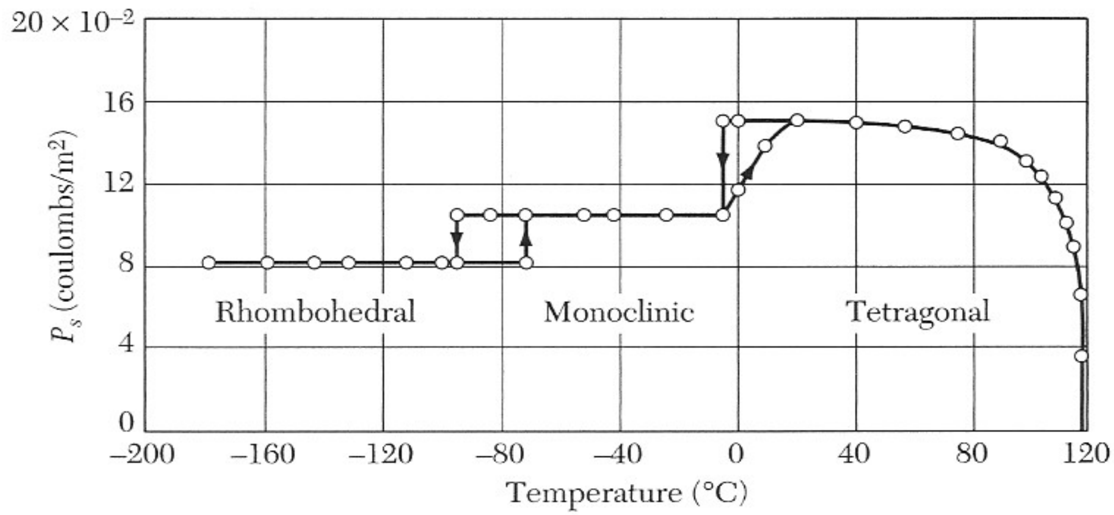
Ferroelectric domains

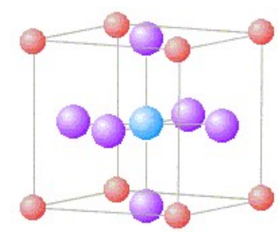


Increasing the electric field polarizes the material.

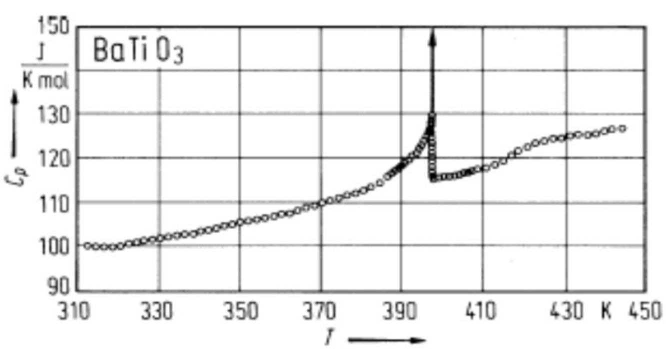
$BaTiO_3$







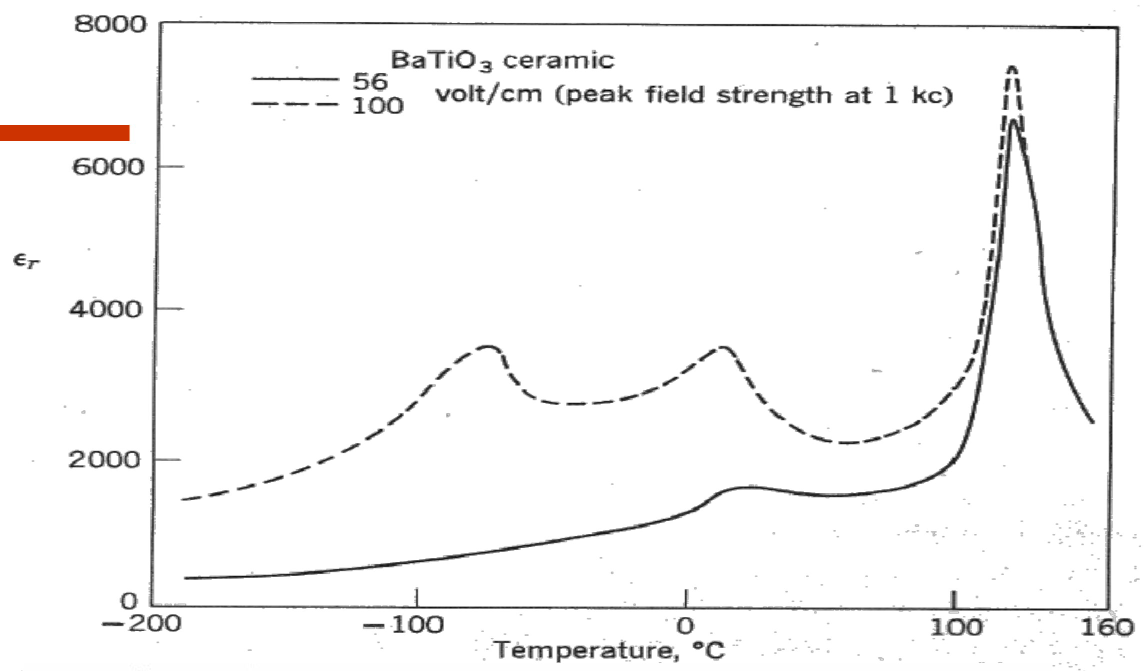
cubic (contains i => no spontaneous P)

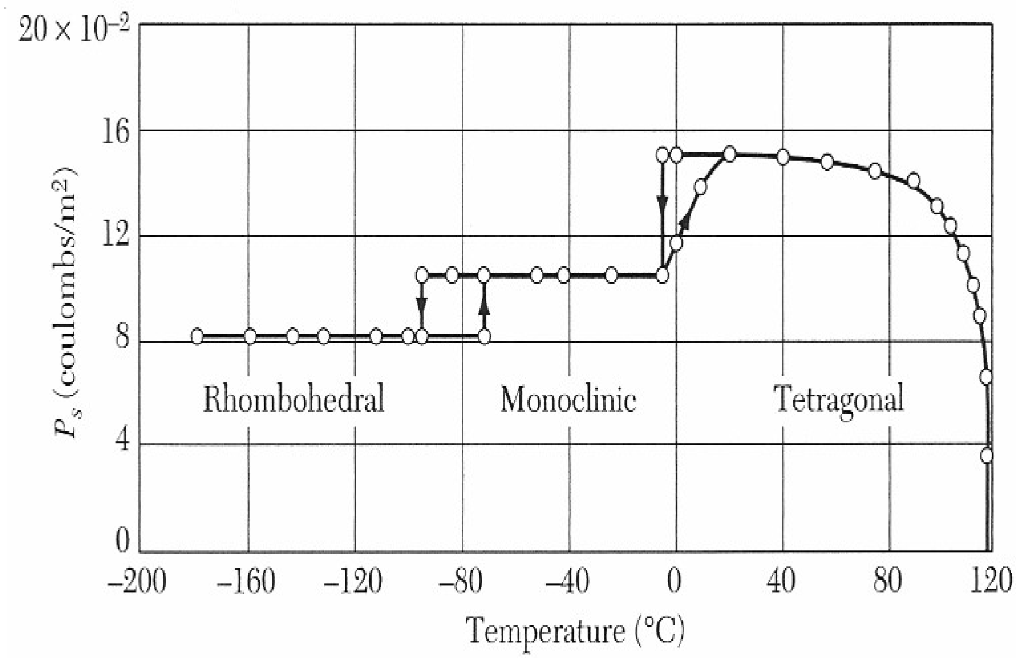


Can be used to make nonvolatile memory

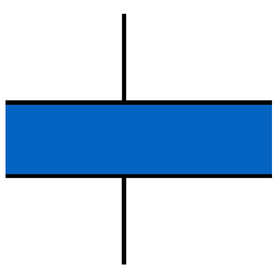
$BaTiO_3$

$$\varepsilon_r = \chi + 1$$





Can be used to make ultracapacitors

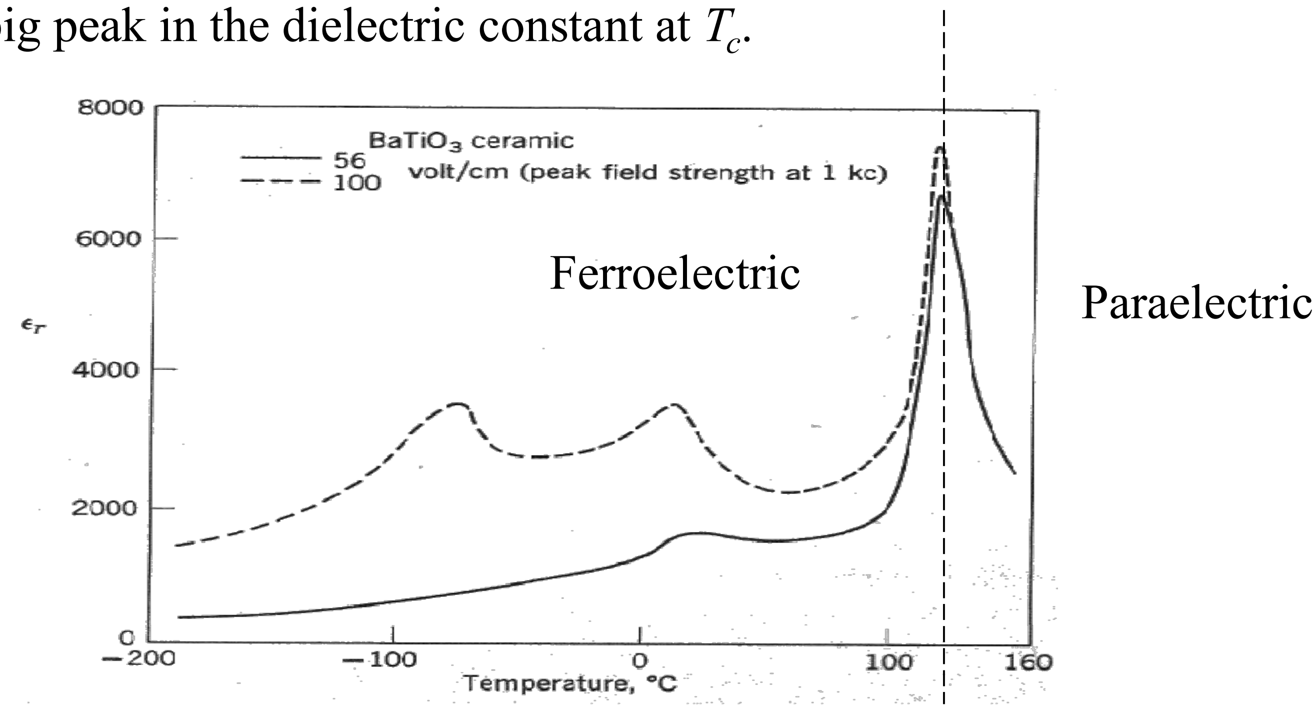


Paraelectric state

Above T_c, $BaTiO_3$ is paraelectric. The susceptibility (and dielectric constant) diverge like a Curie-Weiss law.

$$\chi \propto \frac{1}{T - T_c} \qquad \varepsilon = (1 + \chi)\varepsilon_0$$

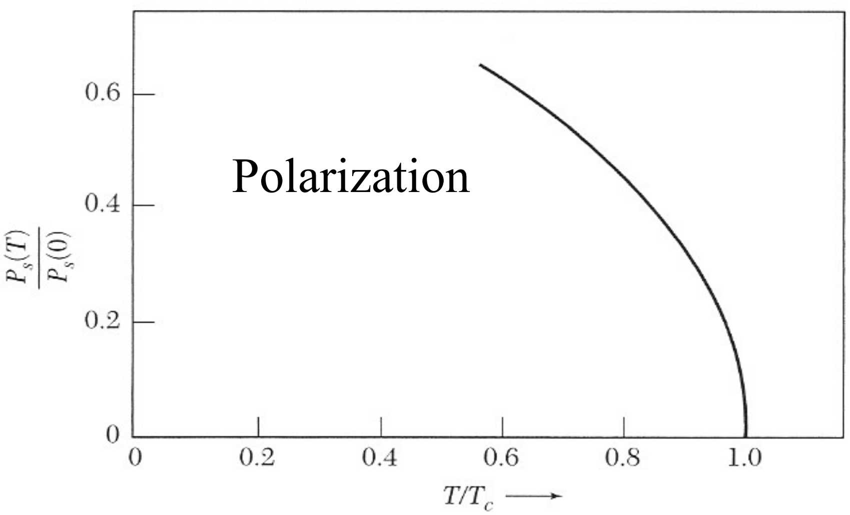
This causes a big peak in the dielectric constant at T_c.

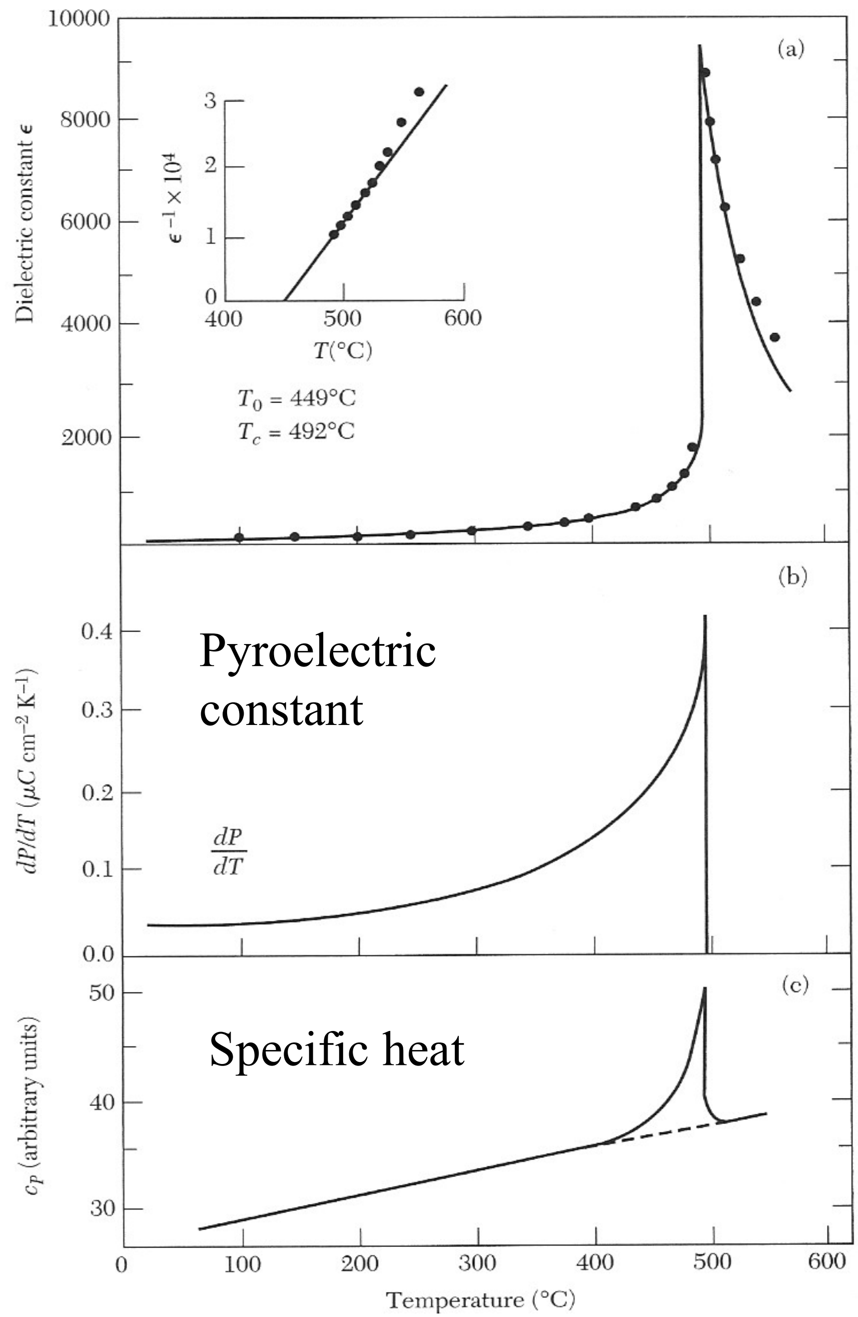


$PbTiO_3$

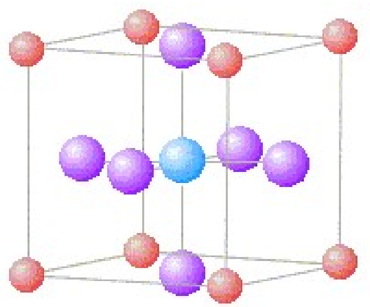
Dielectric constant

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





Antiferroelectricity



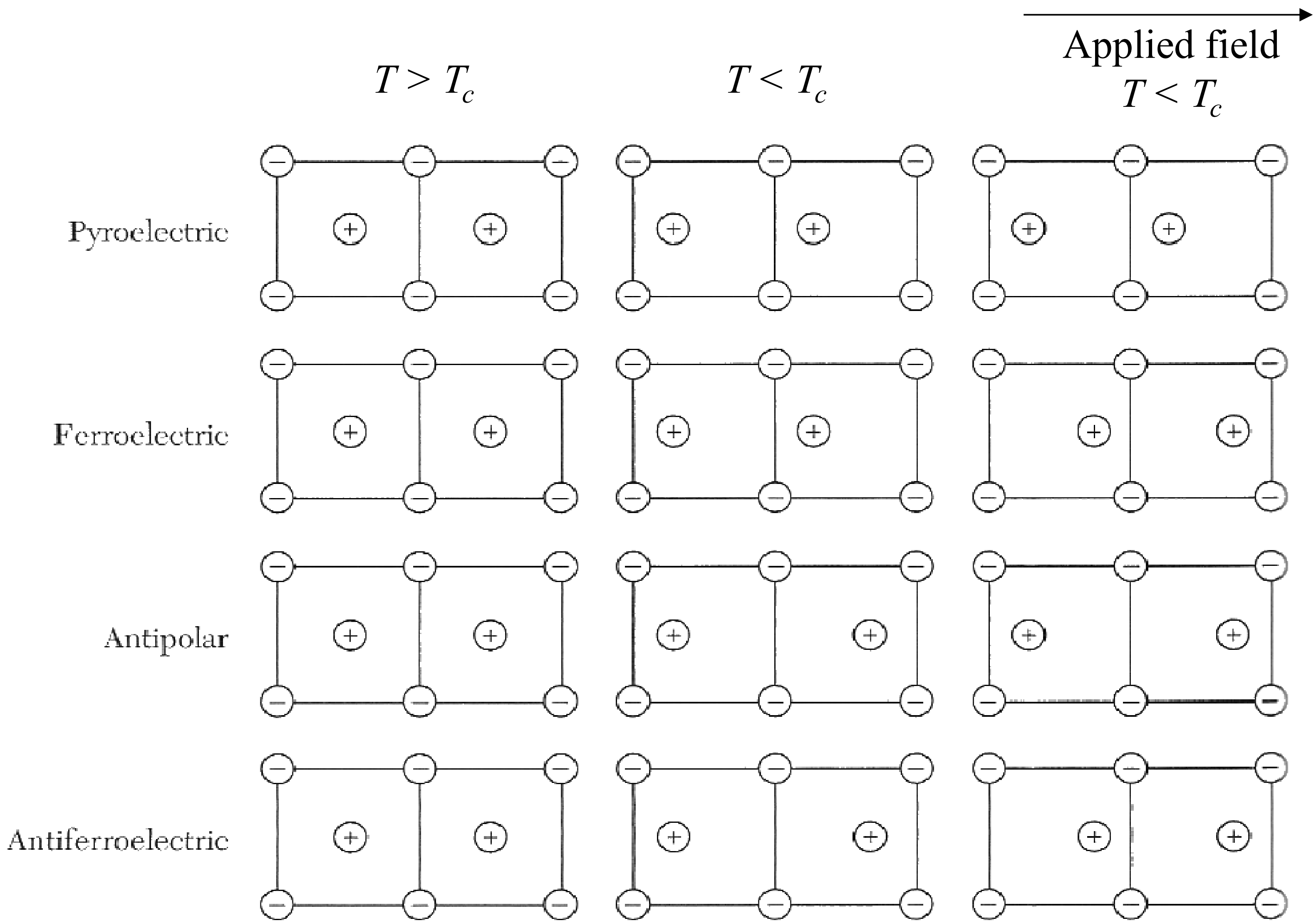
$PbZrO_3$

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.


Applied field
$T > T_c$
$T < T_c$
$T < T_c$
Pyroelectric
Ferroelectric
Antipolar
Antiferroelectric

Piezoelectricity

Many ferroelectrics are piezoelectric.

Electric field couples to polarization, polarization couples to structure.

lead zirconate titanate ($Pb[Zr_xTi_{1-x}]O_3$ $0<x<1$)
—more commonly known as PZT
barium titanate ($BaTiO_3$) $T_c = 408$ K
lead titanate ($PbTiO_3$) $T_c = 765$ K
potassium niobate ($KNbO_3$) $T_c = 708$ K
lithium niobate ($LiNbO_3$) $T_c = 1480$ K
lithium tantalate ($LiTaO_3$) $T_c = 938$ K

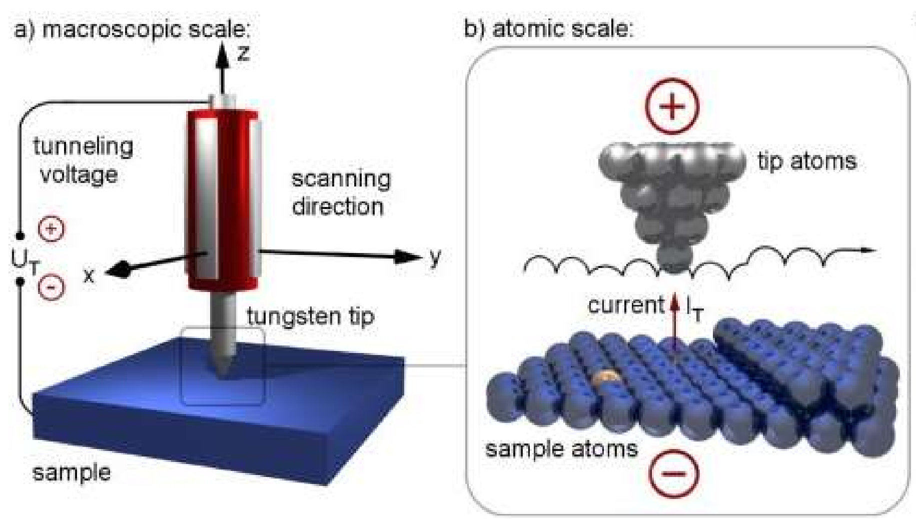
quartz (SiO_2), GaAs, GaN
Gallium Orthophosphate ($GaPO_4$) $T_c = 970$ K

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

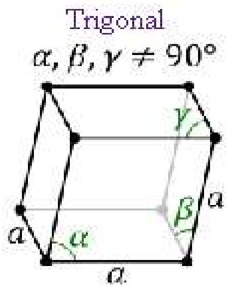
Piezoelectricity

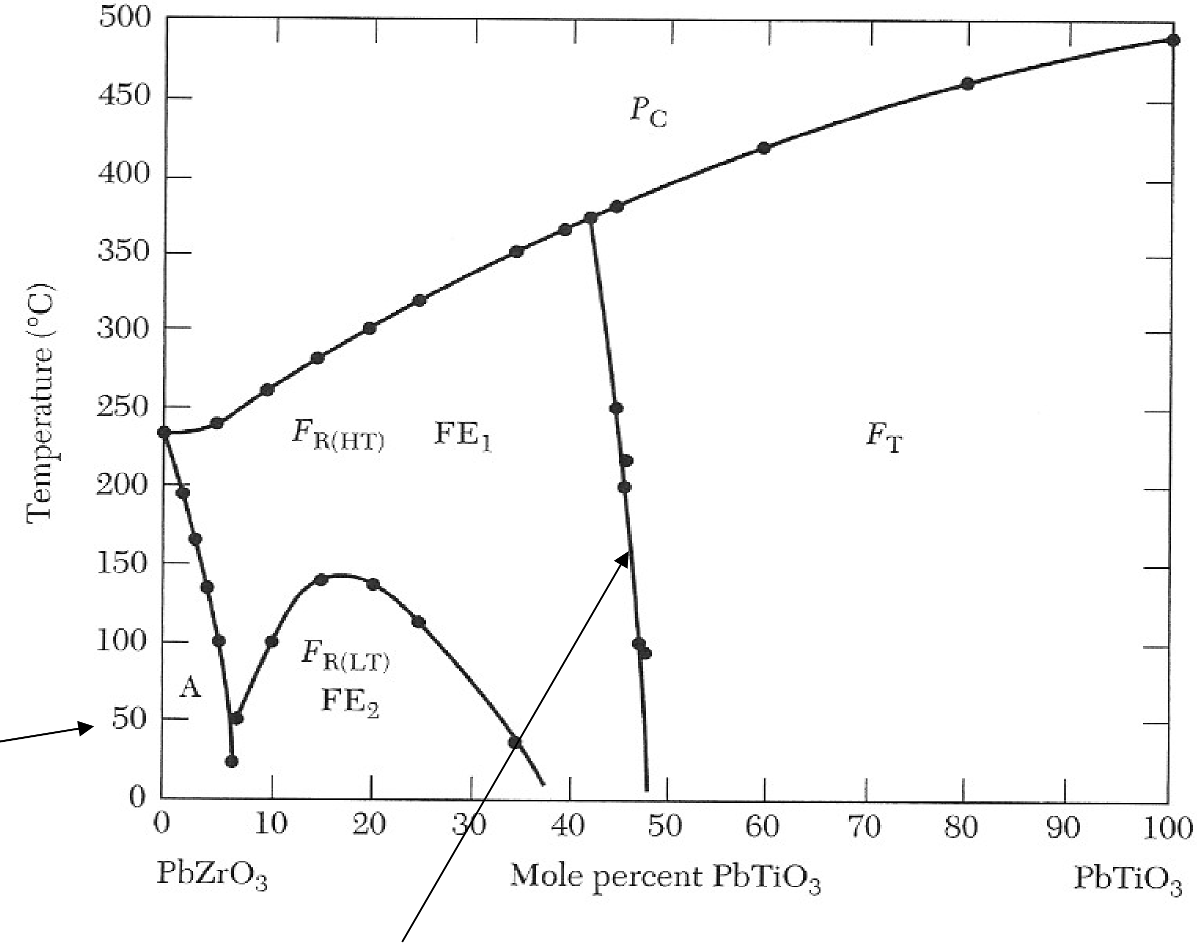
When you apply a voltage across certain crystals, they get longer.

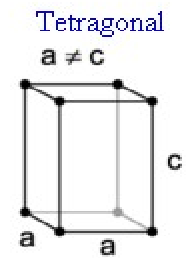


AFM's, STM's
Quartz crystal oscillators
Surface acoustic wave generators
Pressure sensors - Epcos
Fuel injectors - Bosch
Inkjet printers

PZT ($Pb[Zr_xTi_{1-x}]O_3$ $0<x<1$)







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

Return to problem list

Structural and electronic phase transitions

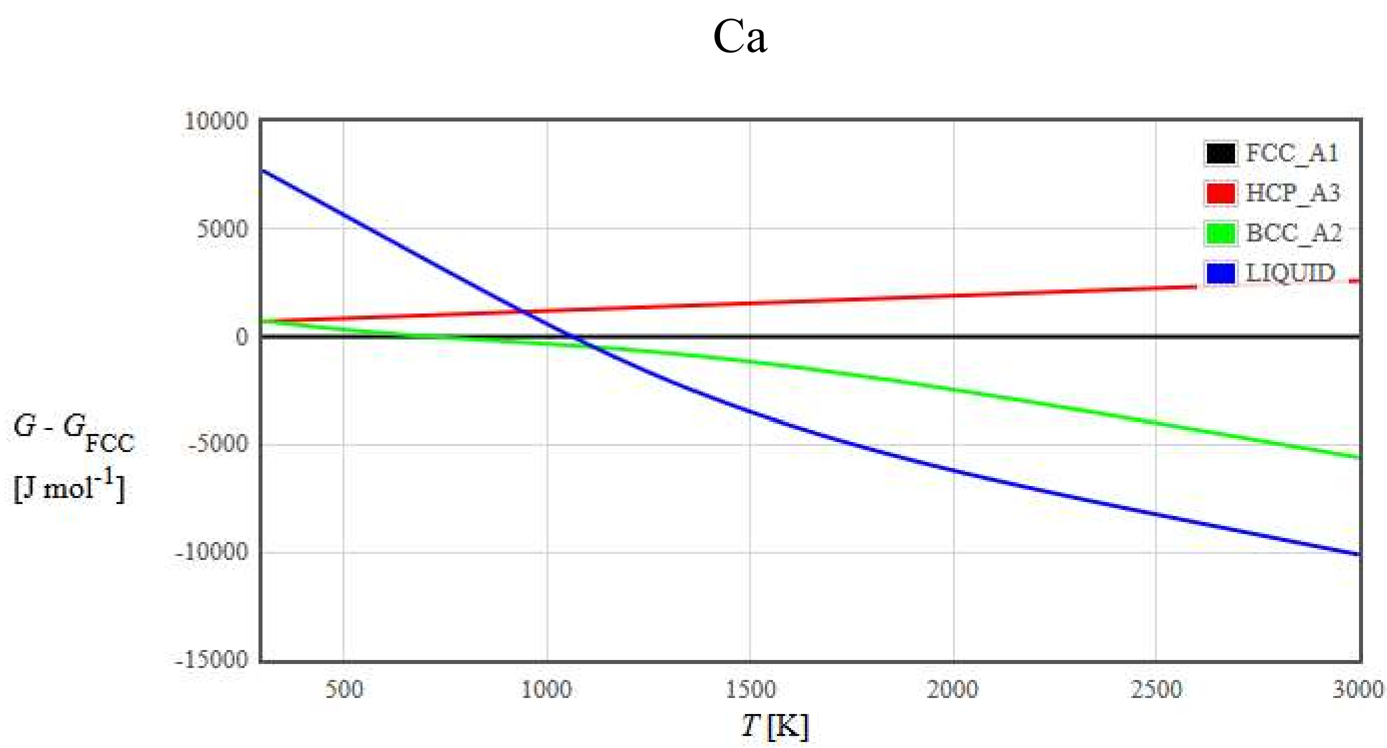
Which of the following phase transitions are associated with a structural phase change?

- superconductivity <-> normal metal
- ferromagnetism <-> paramagnetism
- ferroelectricity <-> paraelectricity
- antiferromagnetism <-> paramagnetism
- antiferroelectricity <-> paraelectricity

Explain your reasoning.

Phase transitions

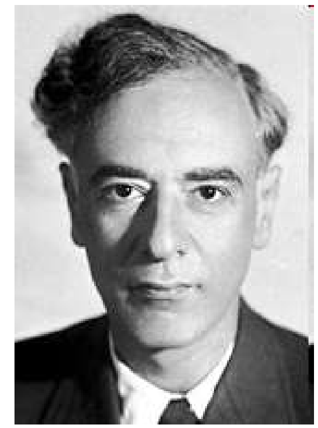
Calculate the free energy of the electrons and phonons of each phase.
See which phase has the lowest energy.



Landau theory of phase transitions

A phase transition is associated with a broken symmetry.

magnetism	direction of magnetization
cubic - tetragonal	different point group
water - ice	translational symmetry
ferroelectric	direction of polarization
superconductivity	gauge symmetry



Lev Landau