2.76/2.760 Multiscale Systems Design & Manufacturing

Fall 2004

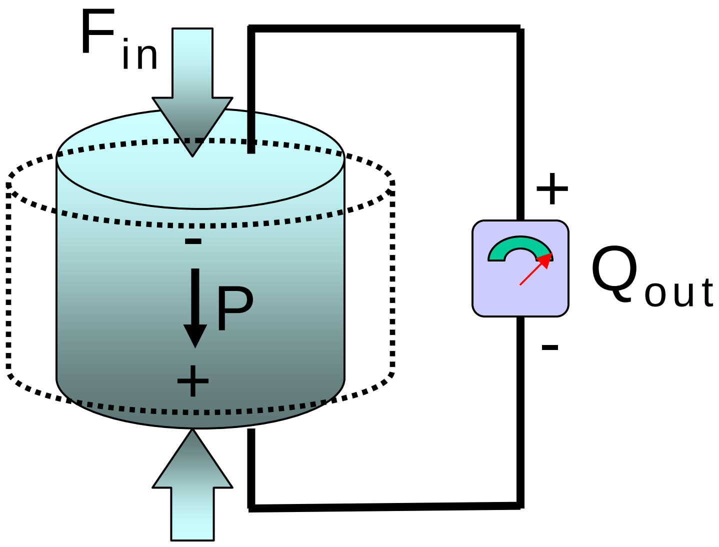
Piezoelectric Transducers

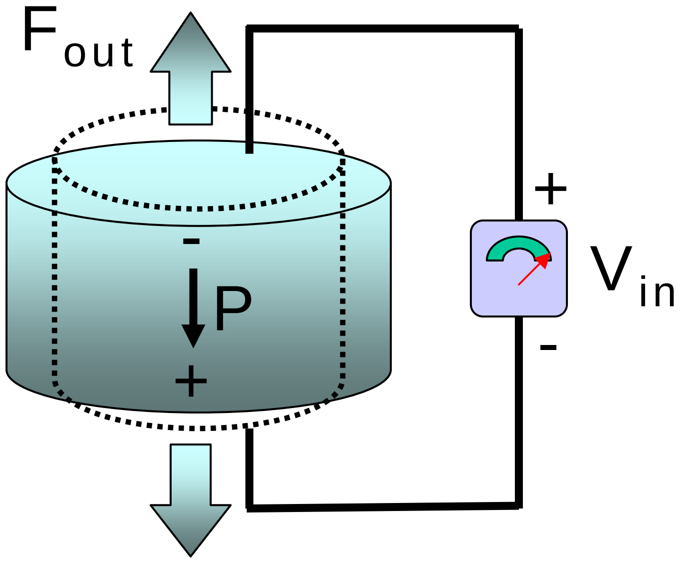
What is Piezoelectricity ?

Jacques & Pierre Curie (1880)

Lippmann (1881)

Electrical Energy ⟺ **Mechanical Energy**





Piezoelectricity

- Piezoelectric Ceramics
- Thin film fabrication

- Piezoelectric Transducers

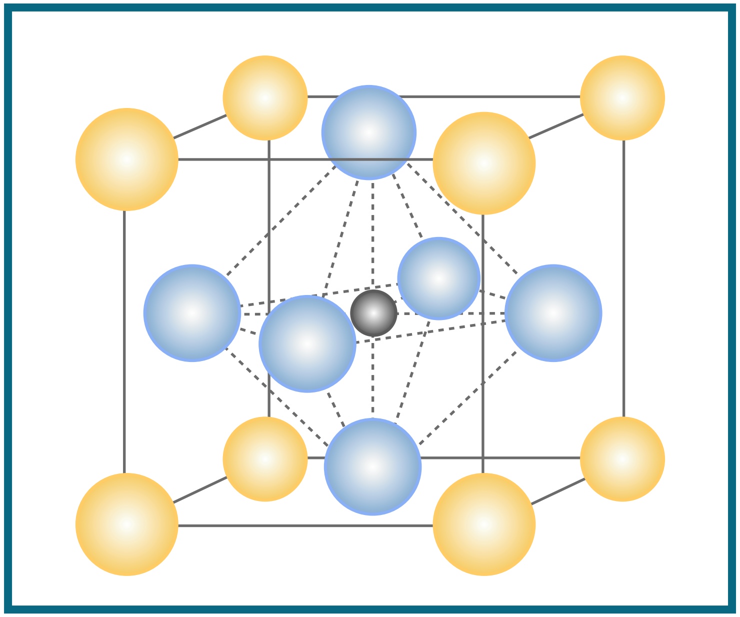


Figure by MIT OCW

Adapted from G. Binnig & H. Rohrer, Nobel Prize, 1986

Photos removed for copyright reasons.
Medical ultrasound, disk drive heads, naval submarine.

Piezoelectric Transducers

1-layer (unimorph)

2-layer

Diagrams removed for copyright reasons.
Source: Piezo Systems, Inc. "Introduction to Piezo Transducers."
http://www.piezo.com/bendedu.html

Transducers

multi-layer (multimorph)

Diagrams removed for copyright reasons.
Source: Piezo Systems, Inc. "Introduction to Piezo Transducers."
http://www.piezo.com/bendedu.html

Component schematic removed for copyright reasons.
Physik Instrumente Z-positioner P-882.10, in http://www.pi-usa.us/pdf/2004_PICatLowRes_www.pdf, page 1-45.

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Dielectric Constant

- Dielectric materials, atoms are ionized, + and – charged, causing electric dipoles. – electric polarization

- Polarization, quantitatively,

  electric dipoles/unit volume, C/m^2

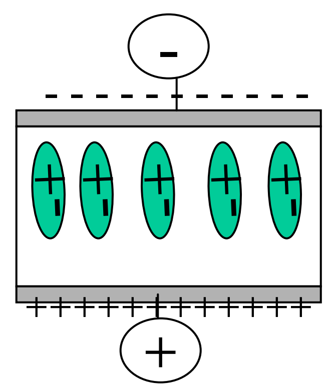
- Dielectric Displacement, D,

  stored electric charge/unit area

$$D = \varepsilon_o + P = \varepsilon E = K\varepsilon_o E$$

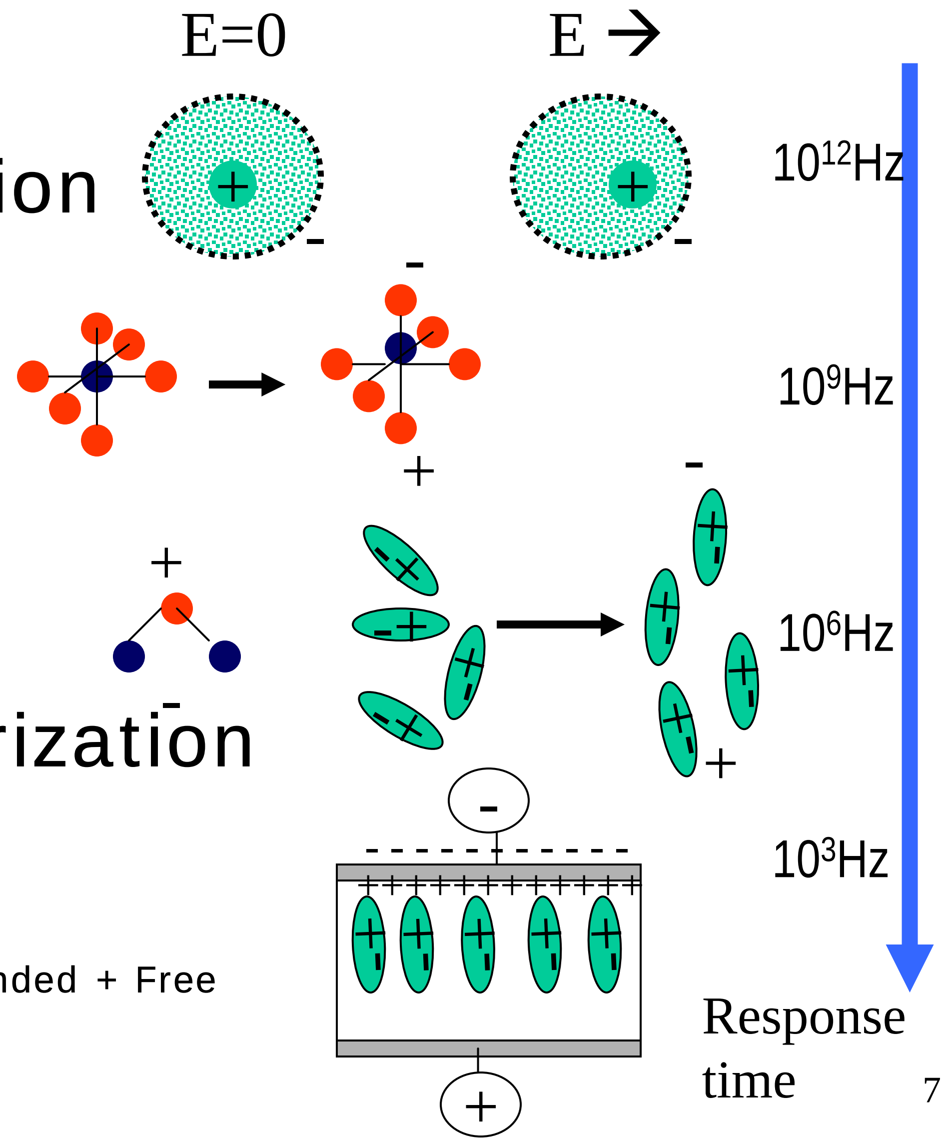
ε_o :Vacuum permittivity (8.854×10^{-12} F/m)

K :Relative Permittivity or dielectric constant



Origins of Polarization

- Electronic Polarization
- Ionic Polarization
  - Ionic crystals, NaCl..
- Dipolar Polarization
  - HCl
- Space Charge Polarization



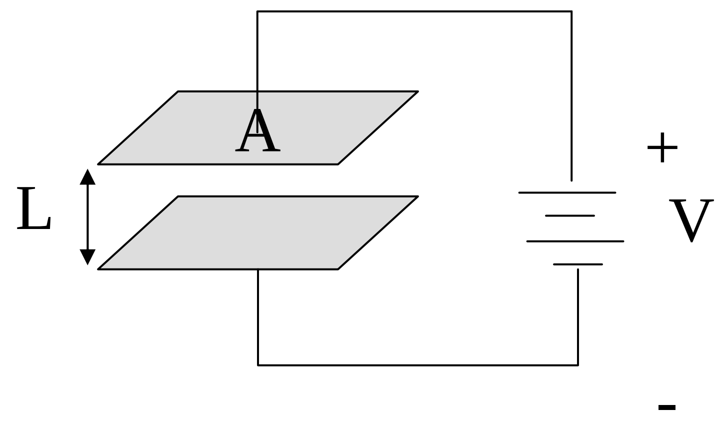
Total Charge= bounded + Free

Capacitance

$$C = \frac{q}{V}$$

Capacitance of a parallel plate capacitor

$$C = \varepsilon\varepsilon_0 \frac{A}{L}$$



Relative Dielectric Constant (K), or permittivity

$$\varepsilon = \frac{C}{C_{Vac}}$$

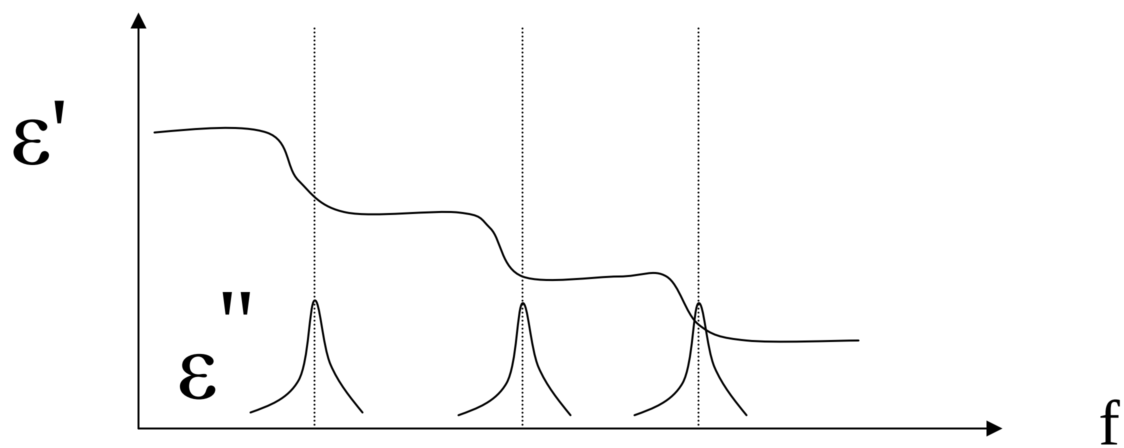
Dielectric Constants

Water	81.1
Silicon	11.8
Glass	6.9
Epoxy	4.0
Ice	3.0
Polyethylene	2.3
Air	1.000576

BaTiO3	6000
KNbO3	700
Rochelle salt	170
PZT	1200

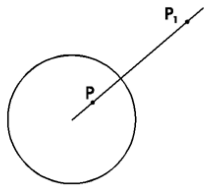
Dielectric Loss

- Frequency dependency of polarization
- When τ and f are in the same order, energy absorbed and phase lag occurs.
- Dielectric Loss, $$\tan\delta = \varepsilon''/\varepsilon'$$
- Dielectric breakdown: 60kV/cm for PZT



Ferroelectricity

- Ionic and electronic polarization
- S^2P or d^0 cations
- Crystal structure with no inversion center



- Ferroelectricity;
  - Spontaneous polarization wrt external electric field
  - Reversible, Remanent polarization, hysterisis
- Pyroelectricity; strong variation in polarization with temperature
- Piezoelectricity; large mechanical strain response to applied electrical field

Perovskite Phase

- PZT, (Pb(Zr_{1-x} Ti_x)O3, the most important piezoelecric material.

  PbZrO3:PbTiO3 → 52:48

  rhombohedral →cubic→tetrahedral

- Curie Temperature

- Pyrochlore phase

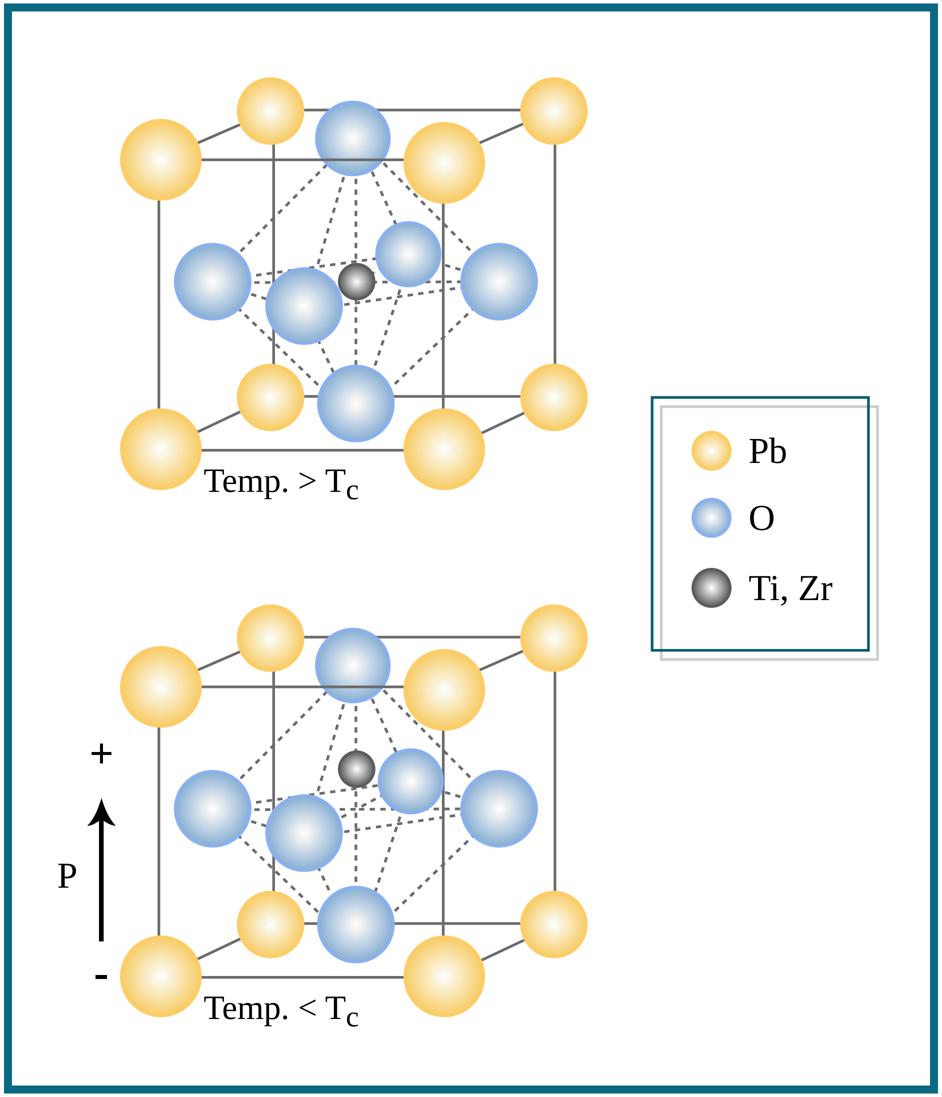


Figure by MIT OCW.

ex) Pb(TixZr1-x)O3(PZT)

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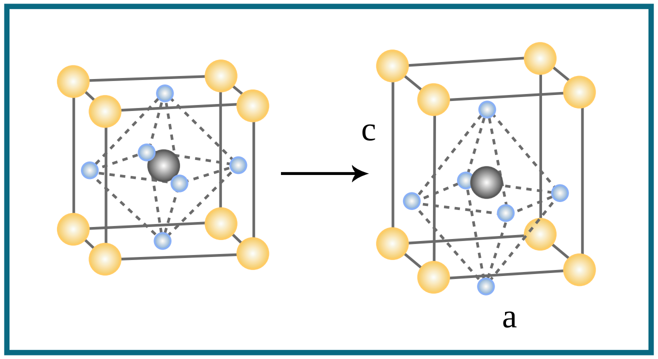
Spontaneous polarization

$$\Delta\vec{P} = \vec{P}(\text{polar}) - \vec{P}(\text{nonpolar}) / a^2c$$

: Polarization per unit cell volume



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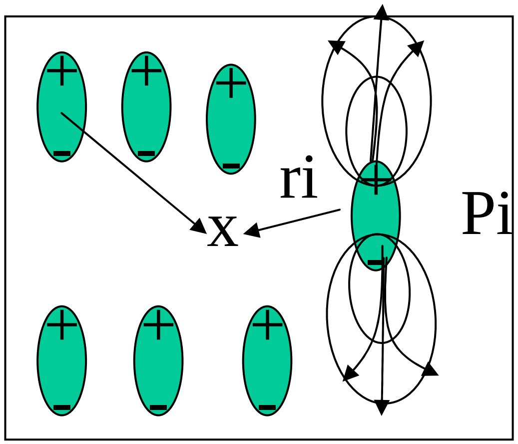

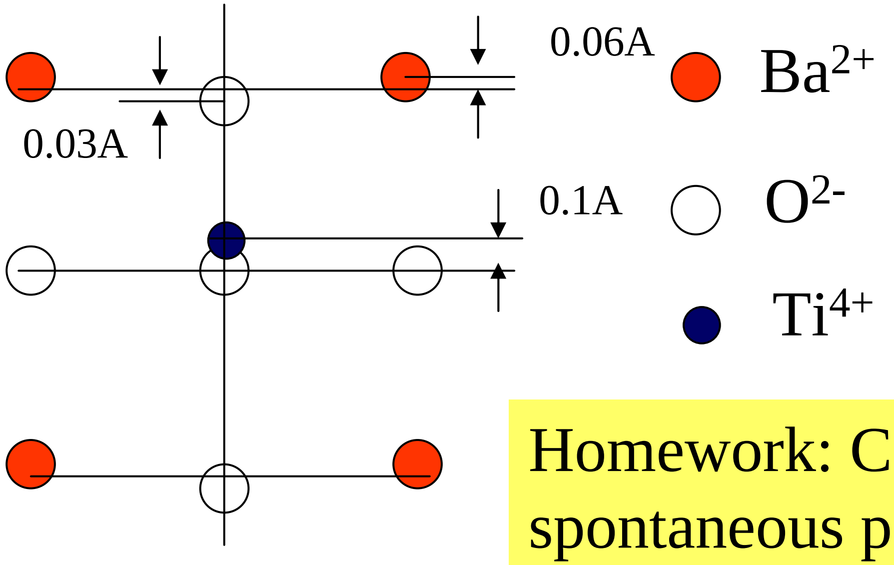

Homework: Calculate the magnitude of spontaneous polarization. a=3.992 A, c=4.036a
1e=1.602×10^{-19} C

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Energy of polarization