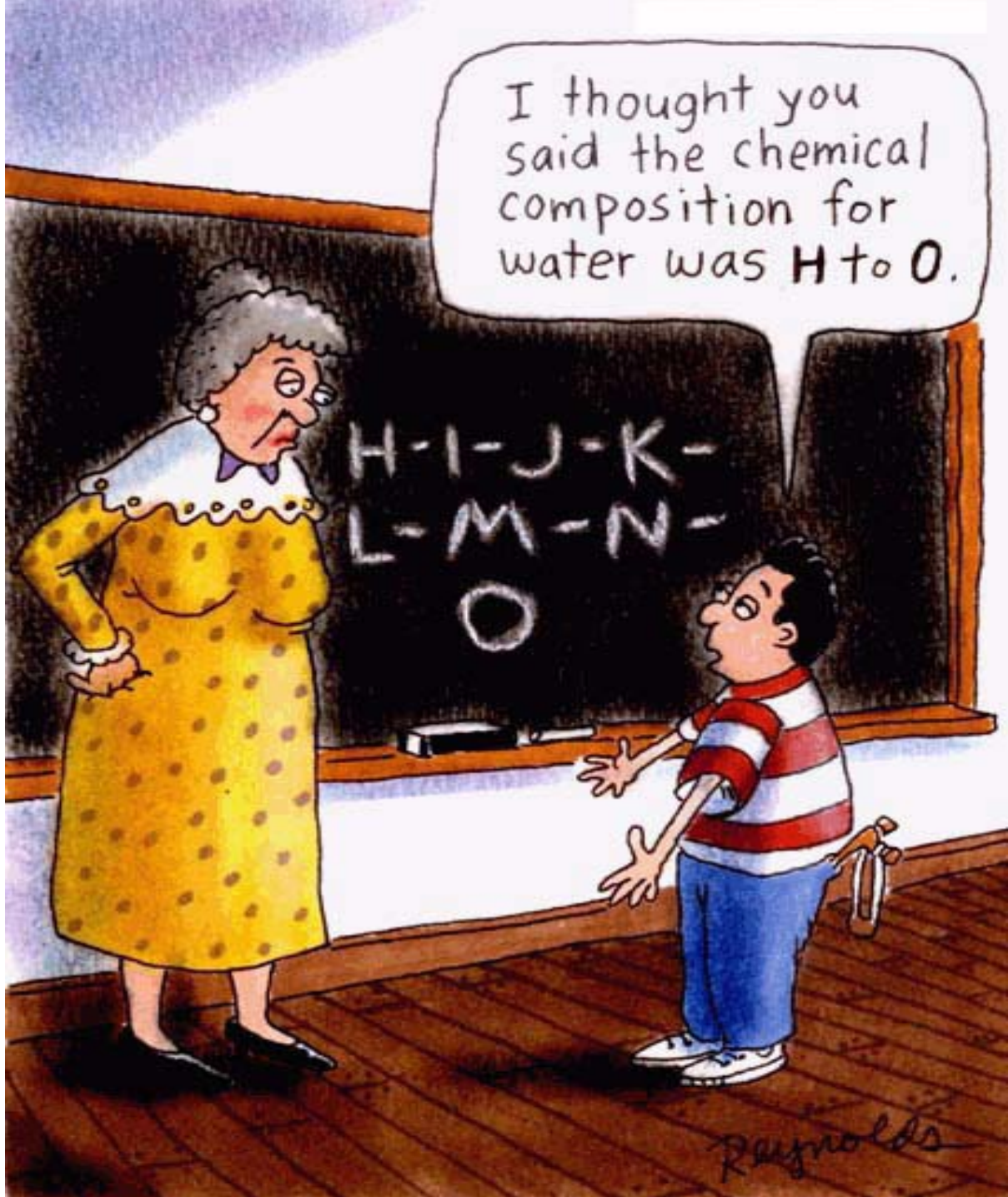
“the difference between the right word and the almost right word is the difference between lightning and a lightning bug”

Mark Twain



The Nature of Dielectric Materials

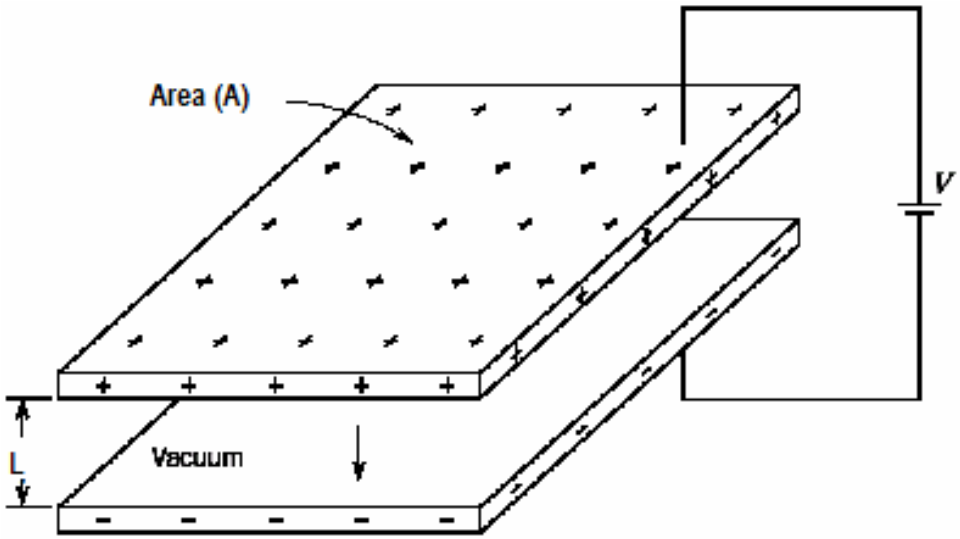
Most solid materials are classified as insulators because they offer very large resistance to the flow of electric current. Metals are classified as conductors because their outer electrons are not tightly bound, but in most materials even the outermost electrons are so tightly bound that there is essentially zero electron flow through them with ordinary voltages. Some materials are particularly good insulators and can be characterized by their high resistivities:

	Resistivity (ohm)
Glass	10^{12}
Mica	9×10^{13}
Quartz (fused)	5×10^{16}

	Resistivity (ohm)
Copper	1.7×10^{-8}

The familiar parallel plate capacitor equation with free space as an insulator under vacuum is given by:

$$C_o = \frac{Q_0}{V} = \frac{\varepsilon_o A}{L}$$



Plates connected to a constant voltage supply ***V***.

Q_o is the charge on the plates.

C_o is the capacitance of the parallel plate capacitor in free space.

ε_o absolute permittivity or the permittivity of a vacuum, the value of 8.85×10^{-12} F/m

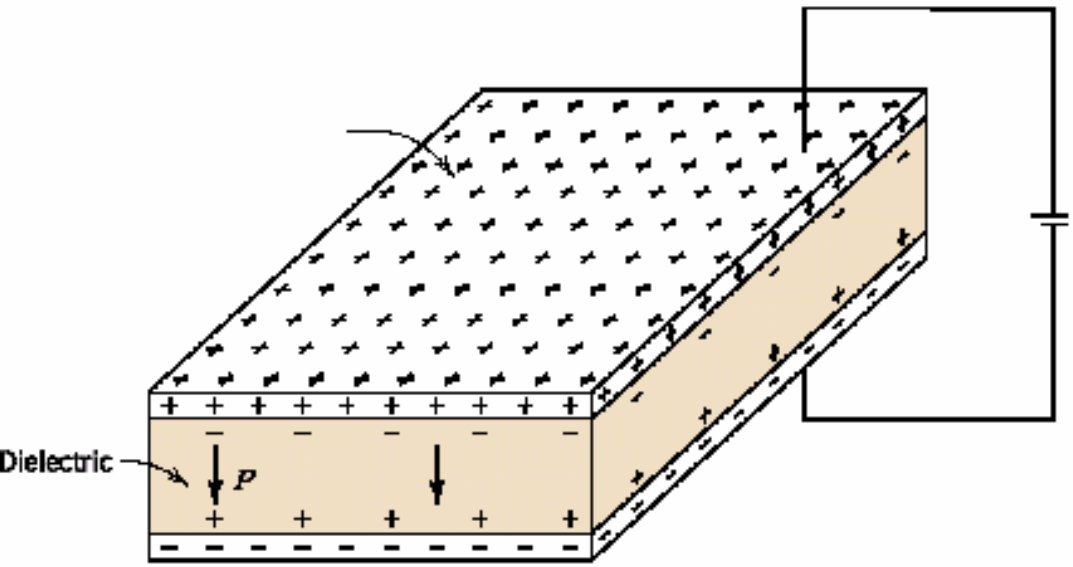
A is the area

L is the separation between the plates

C is the capacitance (charge storage ability per unit voltage)

The electric field E_o is defined as the gradient of the potential then:

$$E_o = \frac{V}{L}$$



If there is a material medium between the plates, then the capacitance (*C*) increases by a factor ε_r, where ε_r is called the *dielectric constant* or *relative permittivity*

Under vacuum

$$C_o = \frac{Q_0}{V} = \frac{\varepsilon_o A}{L}$$

With a material medium

$$C = \frac{Q}{V} = \frac{\varepsilon A}{L}$$

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_o} = \frac{C}{C_o} = \frac{Q}{Q_o}$$

The increase in stored capacity is due to the polarization of the dielectric material by the applied field

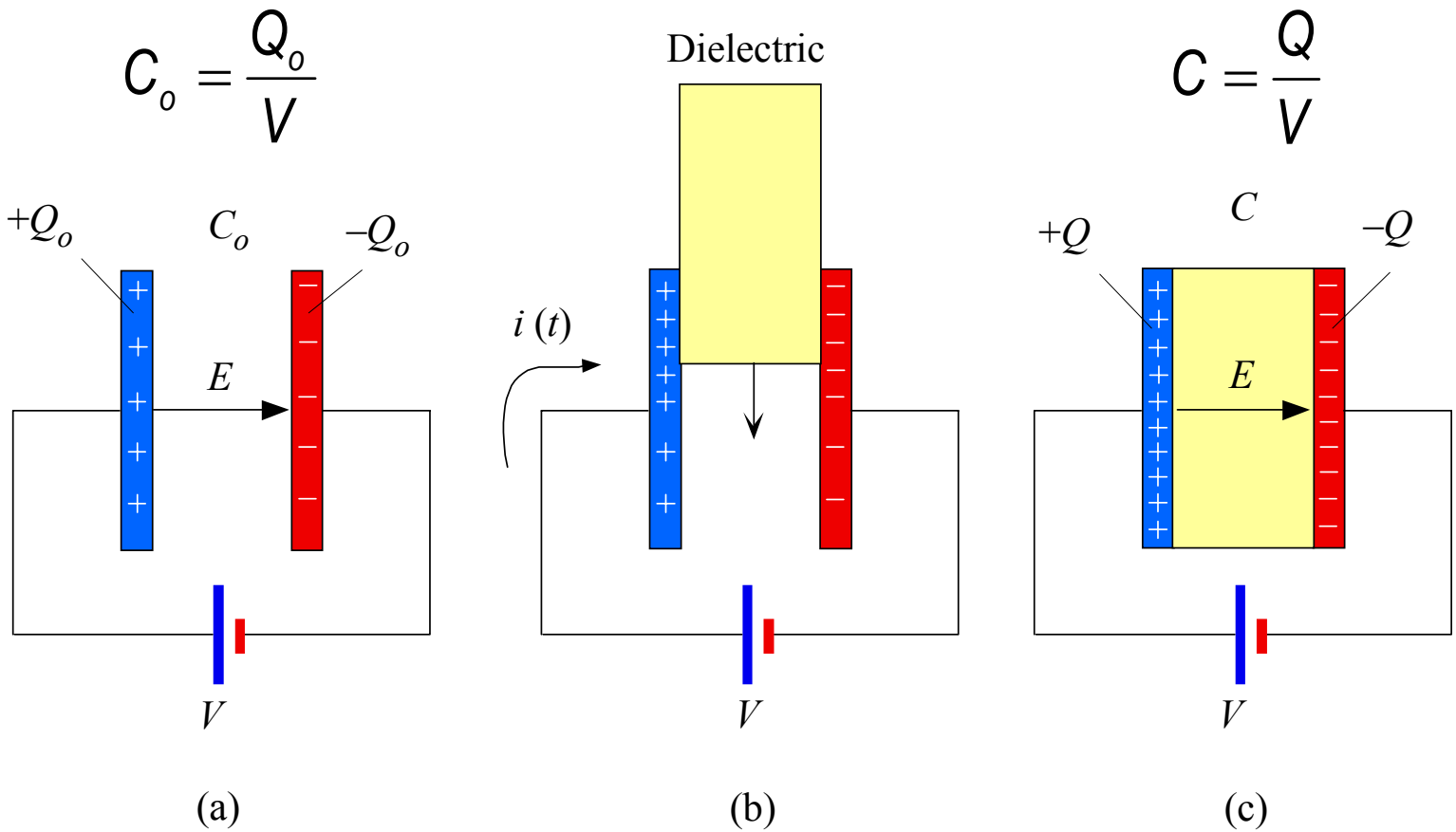
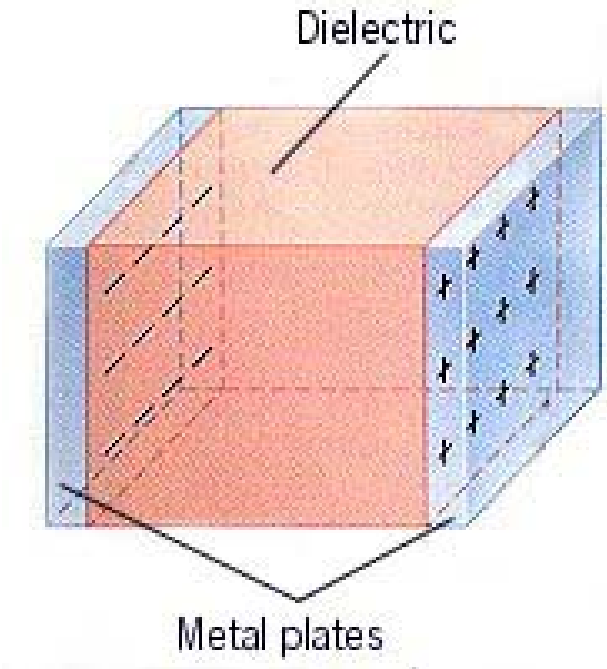
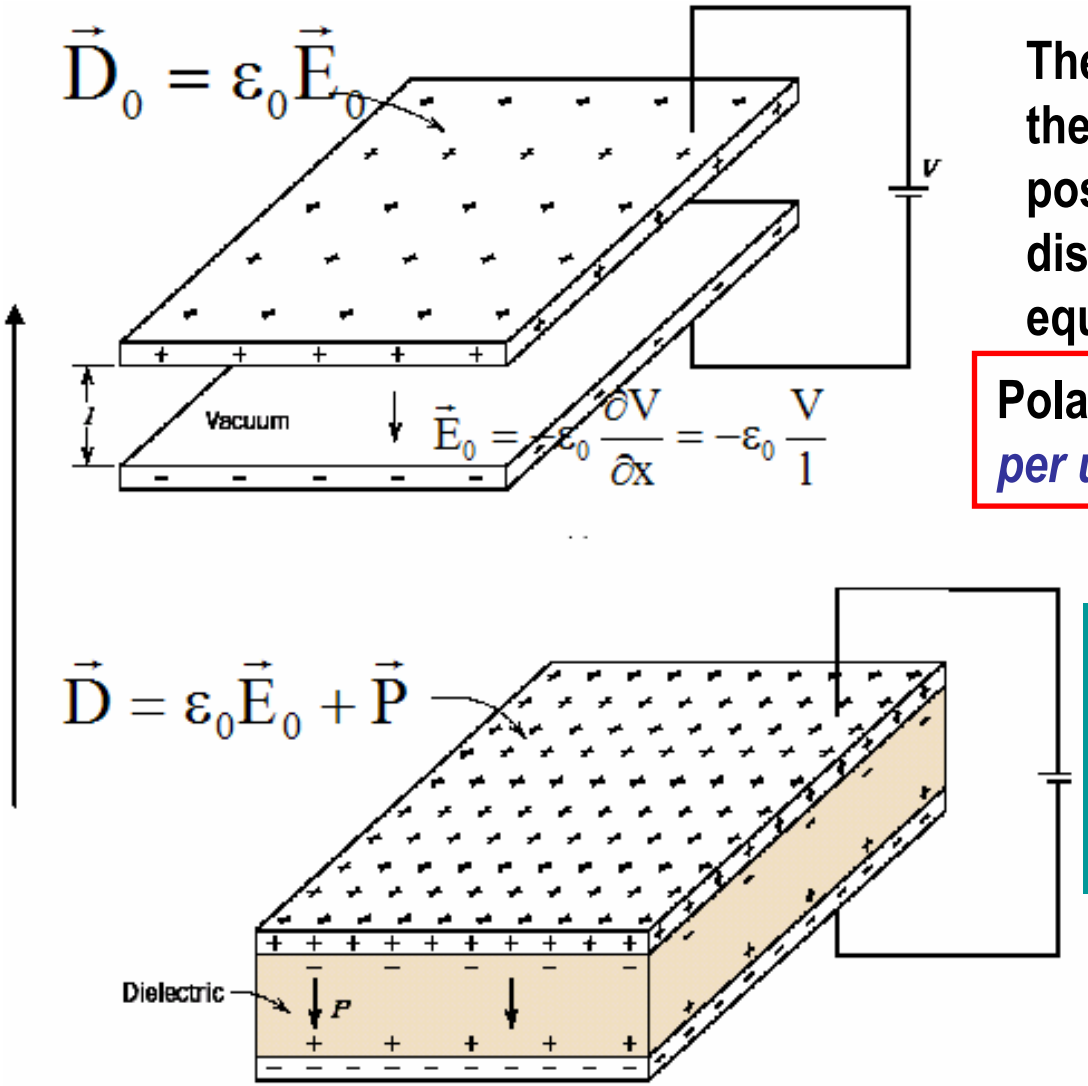


Fig. 7.1: (a) Parallel plate capacitor with free space between plates. (b) As a slab of insulating material is inserted between the plates, there is an external current flow indicating that more charge is stored on the plates. (c) The capacitance has been increased due to the insertion of a medium between the plates.

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A dielectric is any polarizable material. All materials are polarizable, so all materials are dielectrics, even air.



The increase in capacitance is due to the *polarization* of the medium in which positives and negative charges are displaced with respect to their equilibrium position.

Polarization can be viewed as: *Charge per unit area or Dipole per unit volume*

$$\frac{Q}{V} = \varepsilon \frac{A}{L} \Rightarrow \varepsilon = \frac{\left(Q/A\right)}{\left(V/L\right)} = \frac{D}{E_0}$$

E_o is applied electric field, V/m

D - is dielectric displacement = dipole moment per unit volume = charge per unit area, C/m^2

$$D_0 = \varepsilon_0 E_0$$

$$D = \varepsilon E = \varepsilon_r \varepsilon_0 E_0 = D_0 + P$$

Where *P* is the polarization (total dipole moment per unit volume)

$$P = E_0 \varepsilon_0 \left(\varepsilon_r - 1\right)$$

Energy Stored in a Capacitor

The quantity of energy stored in a capacitor is given by the equation

$$Energy = \frac{1}{2} Q \times V = \frac{Q^2}{2C} = \frac{C \times V^2}{2}$$

Dielectric strength

Desired Properties of a dielectric medium:

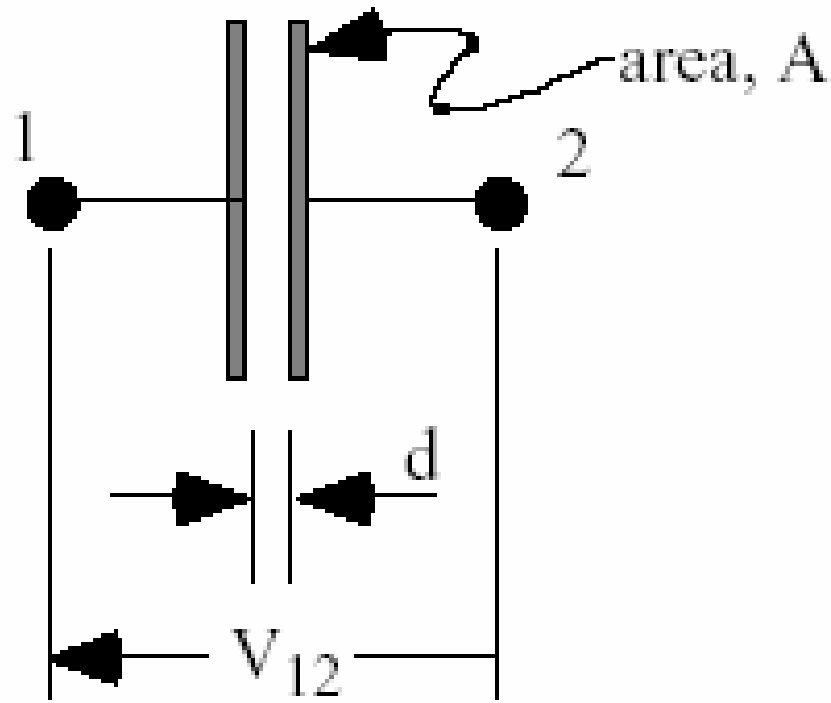
- ability to increase capacitance
- insulating behavior or low conductivity so that the charges are not simply conducted from one plate of the capacitor to the other through the dielectric.

The voltage across the dielectric can not be increased without limit. Very high electric fields (>10^8 V/m) can excite electrons to the conduction band and accelerate them to such high energies that they can, in turn, free other electrons, in an avalanche process (or electrical discharge). The field necessary to start the avalanche process is called **dielectric strength** or breakdown strength. This is the maximum electric field to which a dielectric material can be subjected without breaking down or discharging

Parallel-Plate Capacitor:

We have to design a very large, parallel plate capacitor that will have very tight tolerances on its final dimensions. The area, ***A***, of each of the two plates is ***4.0 m^2***, and the distance between the plates is ***0.50 mm***. Two mediums will be considered for the space between the plates, one is air, ***dielectric constant ε_r=1.00054***, ***(ε_o = 8.85 x 10^{-12} F/m)***, ***dielectric strength = 3 kV/mm***, and a ***0.50 mm thick dielectric paper***, ***dielectric constant ε_r = 3.5, dielectric strength = 16 kV/mm.***

a. Determine the **capacitance C** of the two plates with air.
b. Determine the **capacitance C'** of the two plates with the 0.50 mm thick dielectric paper.
c. What is the **maximum voltage**, $\mathbf{V_{12}}$, can be applied to the capacitor before there is a breakdown of the paper dielectric?



Solution:

a) Capacitance in air $C = \frac{Q}{V} = \frac{\varepsilon A}{L}$ $\varepsilon_r = \frac{\varepsilon}{\varepsilon_o} = \frac{C}{C_o} = \frac{Q}{Q_o}$

$$C = \varepsilon_r \varepsilon_o \frac{A}{L} = (1.00054) \times (8.85 \ x \ 10^{-12} \ F/m) \frac{4.0 m^2}{0.5 \times 10^{-3} m}$$

$$C = 7.12 \times 10^{-8} \, Farads$$

b) Capacitance in paper

$$C' = \varepsilon_r \varepsilon_o \frac{A}{L} = (3.50) \times (8.85 \ x \ 10^{-12} \ F/m) \frac{4.0 m^2}{0.5 \times 10^{-3} m}$$

$$C' = 24.78 \times 10^{-8} \, Farads$$

c) Maximum Voltage $E = \frac{V_{12}}{L} \rightarrow V_{12} = E \times L = (16 kV/mm) \times (0.5 mm) = 8 kV$

Example

Polyethylene has a polarization of $5.75 \times 10^{-8} C.m^{-2}$ in a field of $5000 V.m^{-1}$. Calculate the dielectric constant of this polymer.

Solution

$$P = E_0 \varepsilon_0 (\varepsilon_r - 1)$$

$$\varepsilon_r = 1 + \frac{P}{E_0 \varepsilon_0} = 1 + \frac{\left(5.75 \times 10^{-8} C.m^{-2}\right)}{\left(5000 V.m^{-1}\right) \times \left(8.85 \times 10^{-12} F.m^{-1}\right)}$$

$$\varepsilon_r = 2.3$$

Dielectric Behavior

Mechanisms:dipole formation/orientation

- electronic (induced) polarization: Applied electric field displaces negative electron “clouds” with respect to positive nucleus.
- Ionic materials (induced) polarization: Applied electric field displaces cations and anions in opposite directions
- molecular (orientation) polarization: Some materials possess permanent electric dipoles (e.g. H_2O). In absence of electric field, dipoles are randomly oriented. Applying electric field aligns these dipoles, causing net (large) dipole moment.

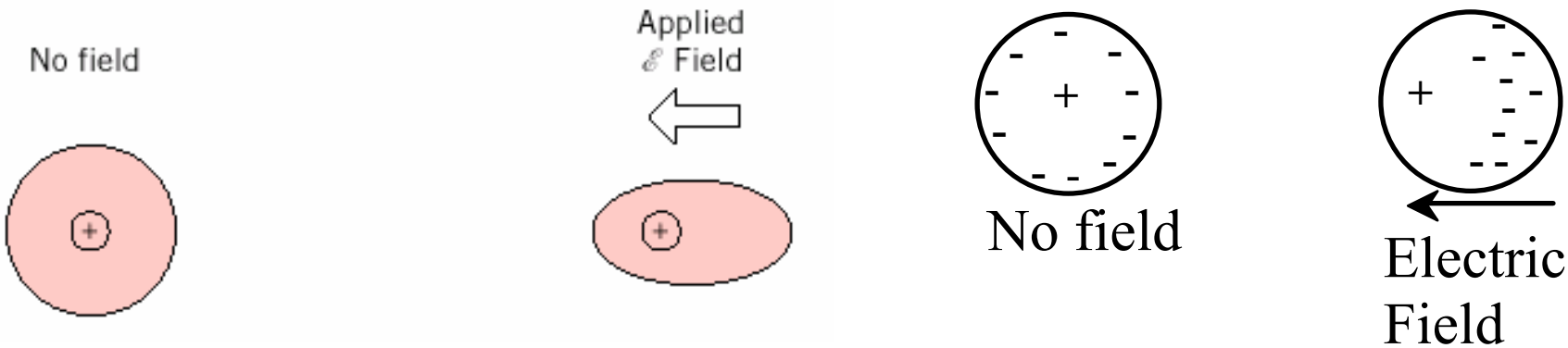
$$P_{total} = P_e + P_i + P_o$$

Types or Mechanism of Polarization

Electronic Polarization

It may be induced (to some degree) in all atoms

Displacement of the center of the negative electron cloud off the nucleus (only present when there is an electric field)



electronic polarization

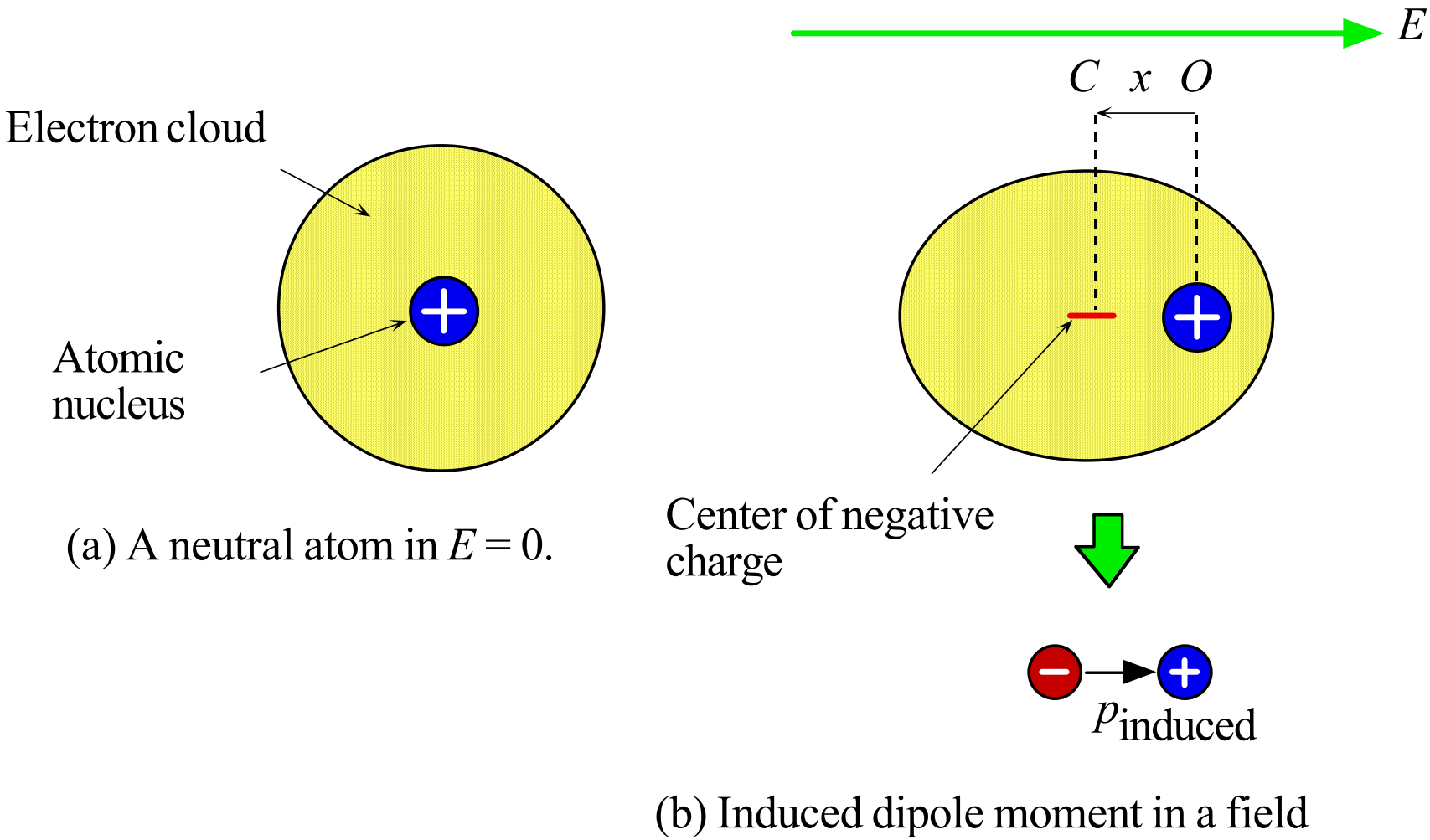
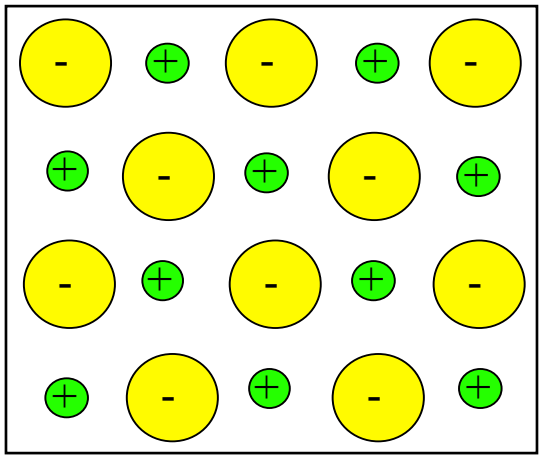


Fig. 7.3: The origin of electronic polarization.

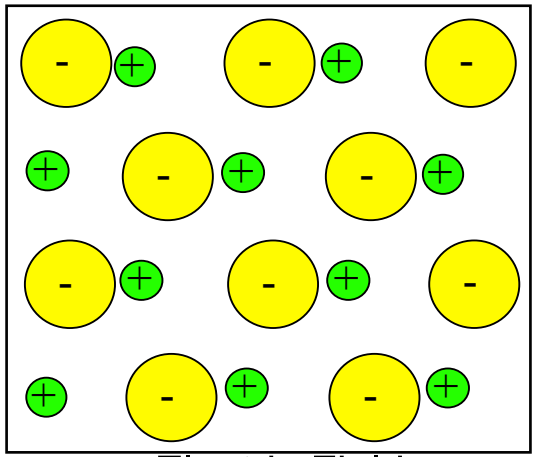
The magnitude of the electric dipole moment is ***P = q x d,*** where d is the distance between dipoles

Ionic Polarization - Only occurs in ionic materials

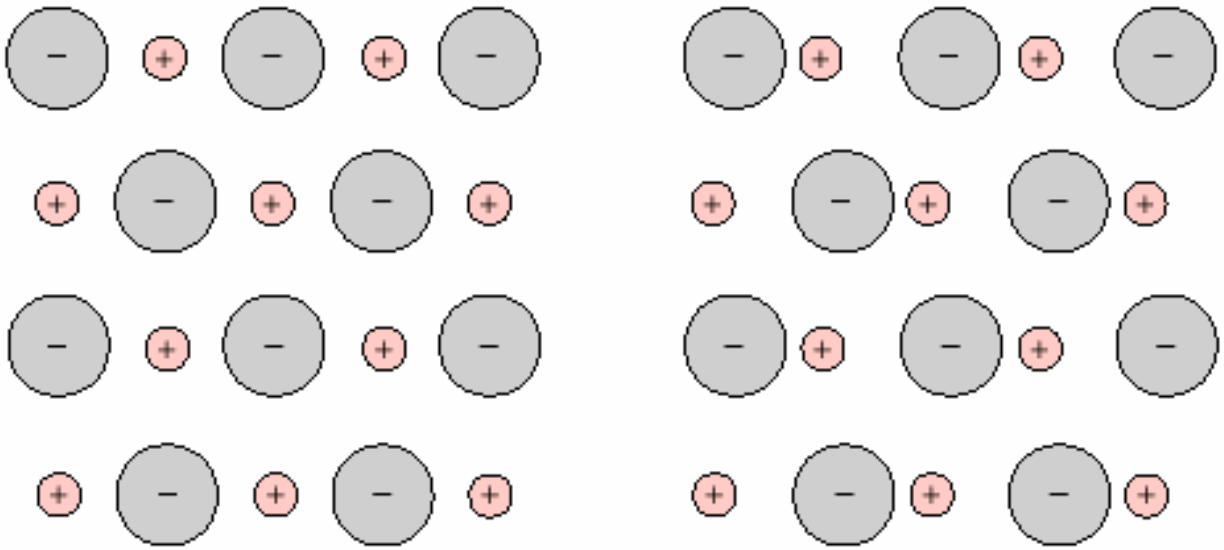
An applied field displaces cations in one direction and anions in another:



No electric field



Electric Field



ionic polarization

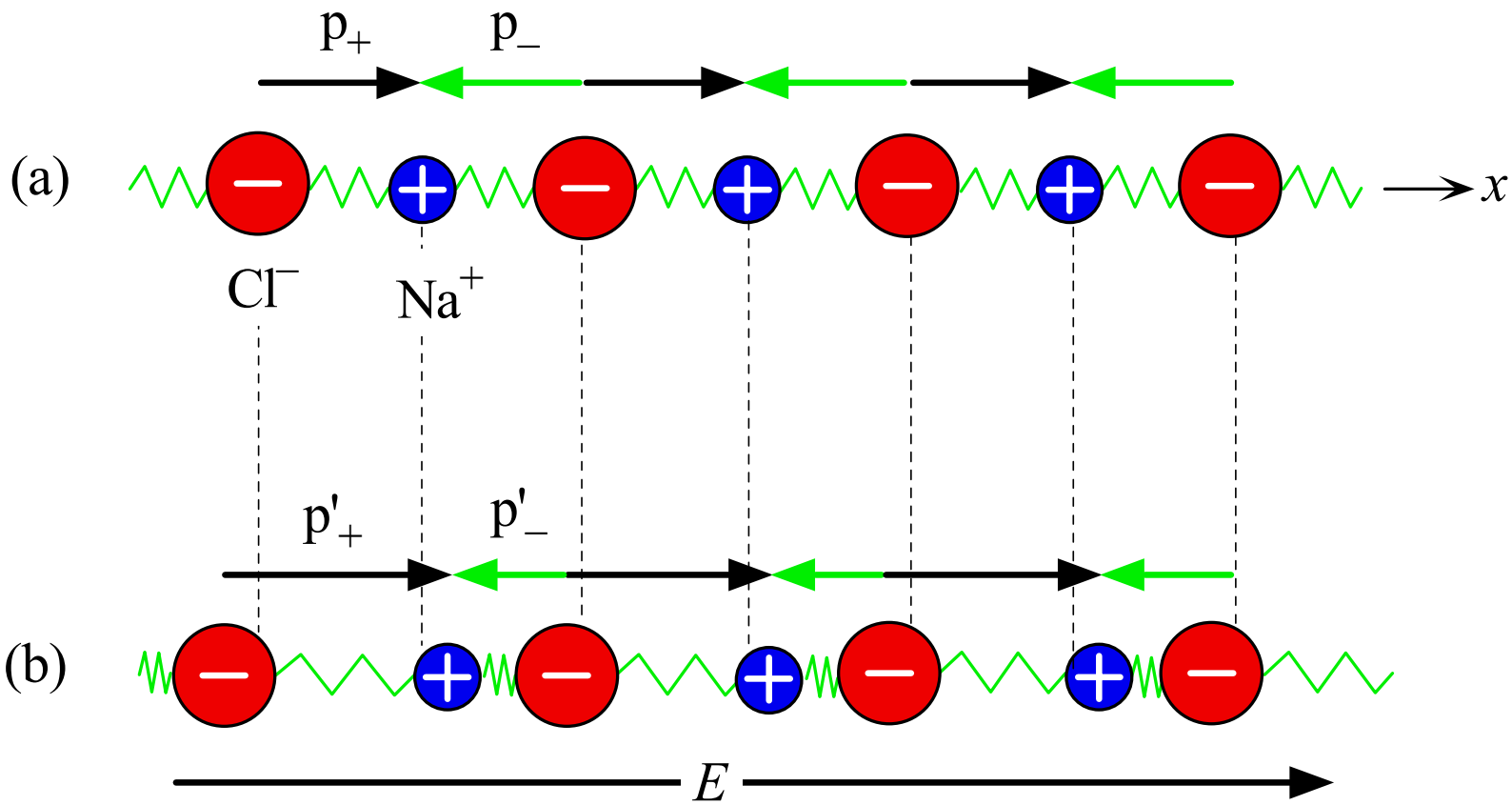
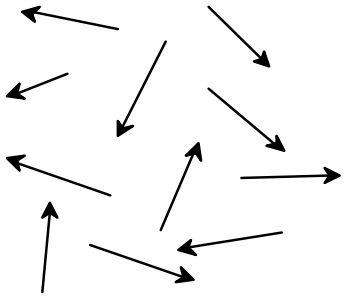


Fig. 7.8: (a) A NaCl chain in the NaCl crystal without an applied field. Average or net dipole moment per ion is zero. (b) In the presence of an applied field the ions become slightly displaced which leads to a net average dipole moment per ion.

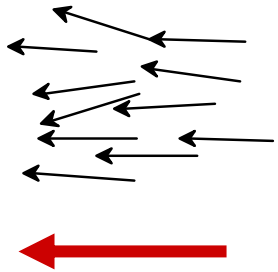
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Orientation Polarization

Only in materials which possess permanent dipole moments

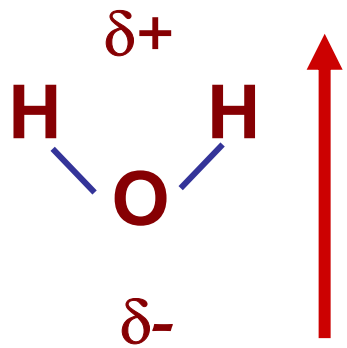


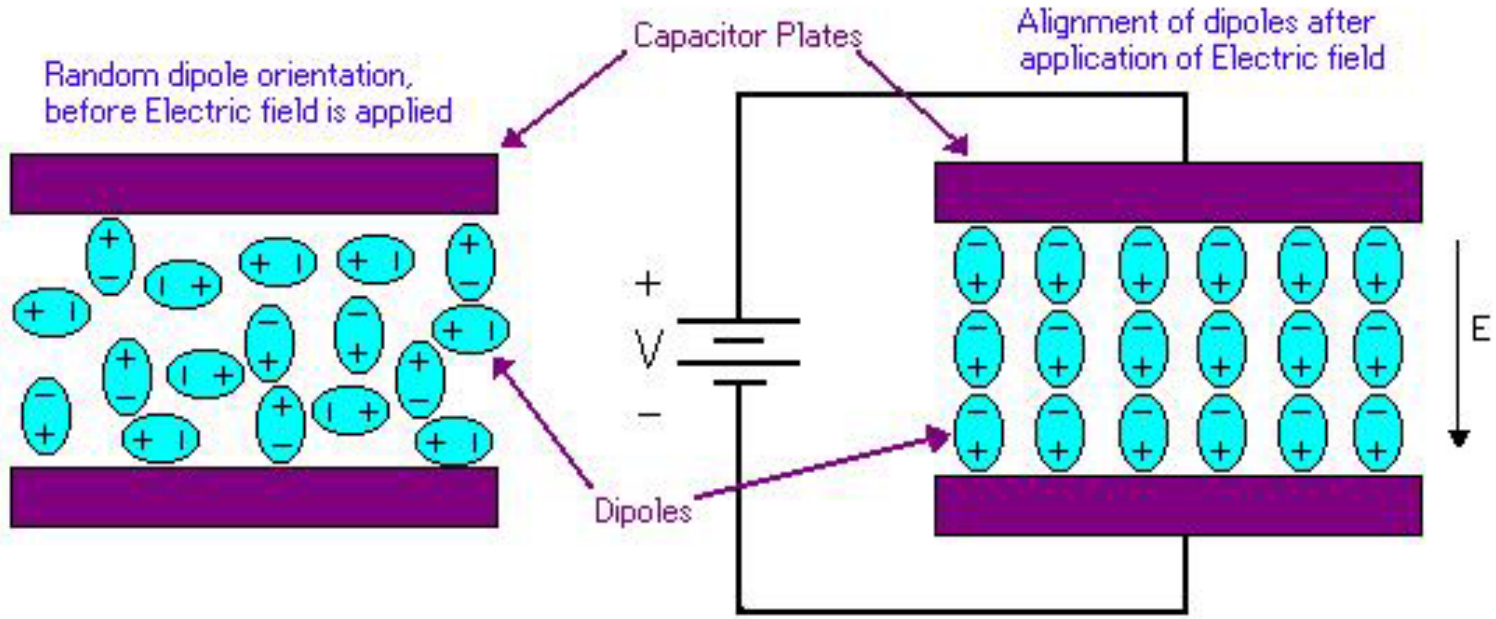
No field



Electric Field

example





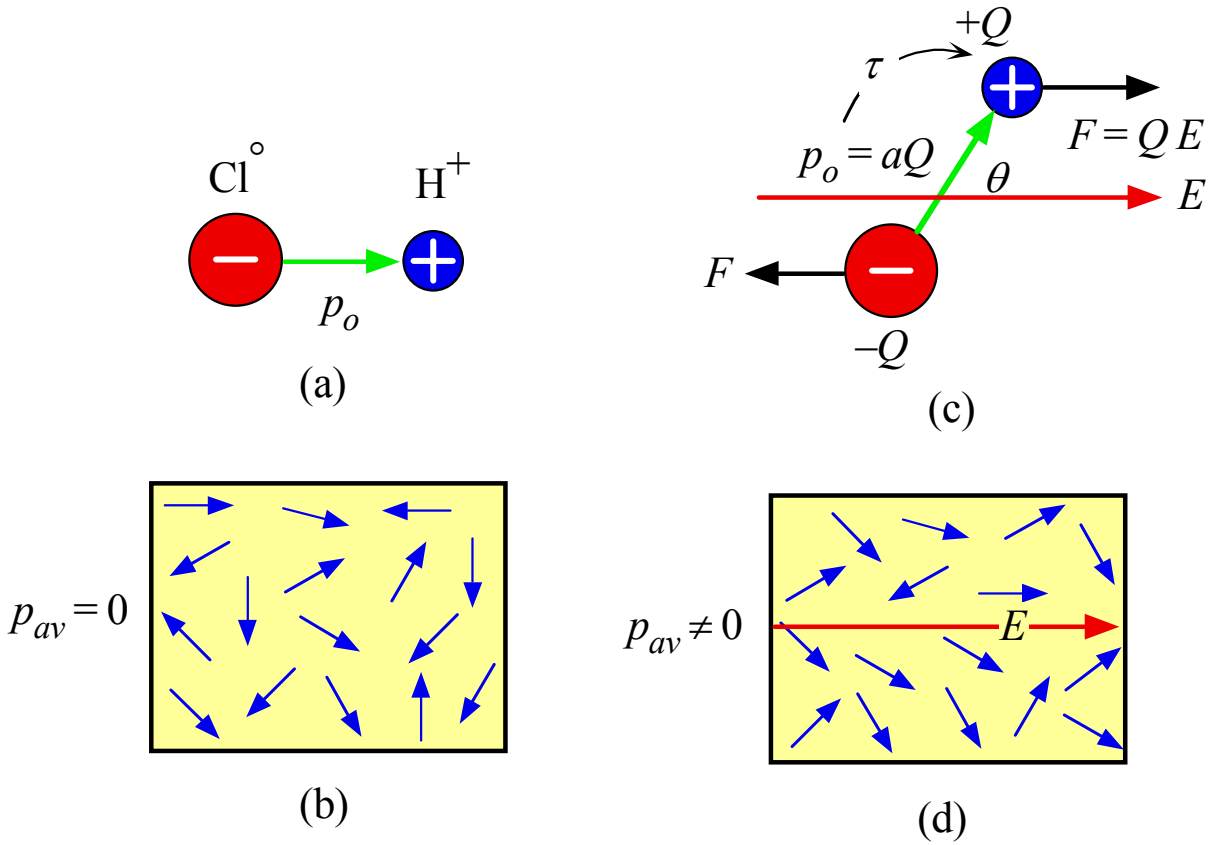
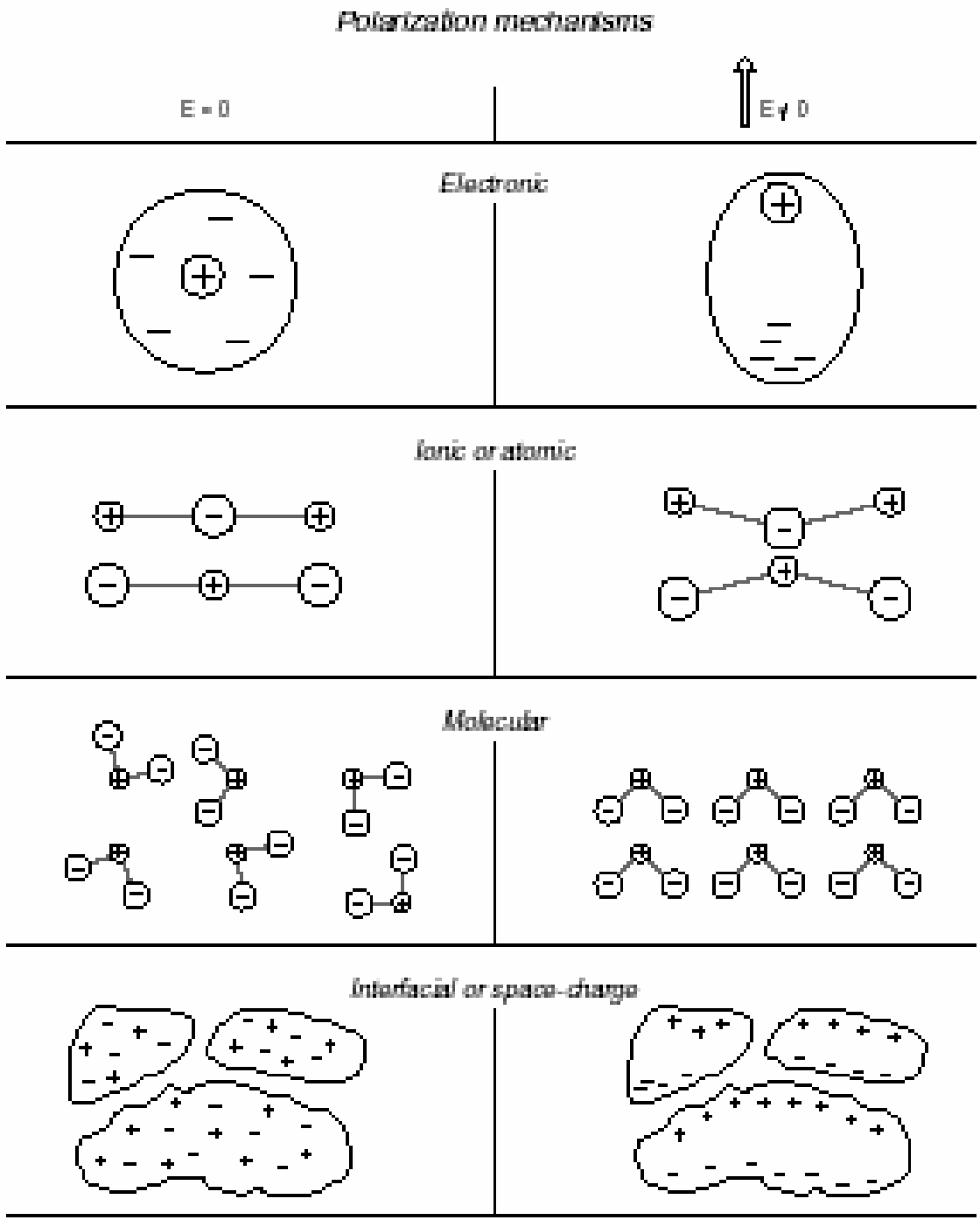


Fig. 7.9: (a) A HCl molecule possesses a permanent dipole moment, p_O (b) In the absence of a field, thermal agitation of the molecules results in zero net average dipole moment per molecule. (c) A dipole such as HCl placed in a field experiences a torque which tries to rotate it to align p_O with the field E. (d) In the presence of an applied field the dipoles try to rotate to align with the field against thermal agitation. There is now a net average dipole moment per molecule along the field.

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Polarization mechanisms
E = 0
E ≠ 0
Electronic
Ionic or atomic
Molecular
Interfacial or space-charge

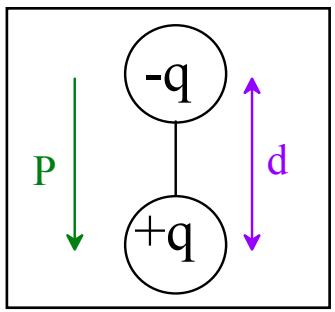
Total Polarization: $P = P_e + P_i + P_o$

(electronic + ionic + orientation)

Capacitors

Parallel plate capacitor. Apply a voltage; charge ***Q*** accumulates on the plates

Place a material between the plates - ***Q*** increases e.g. ***H_2O***

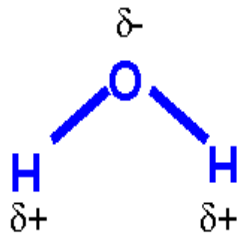


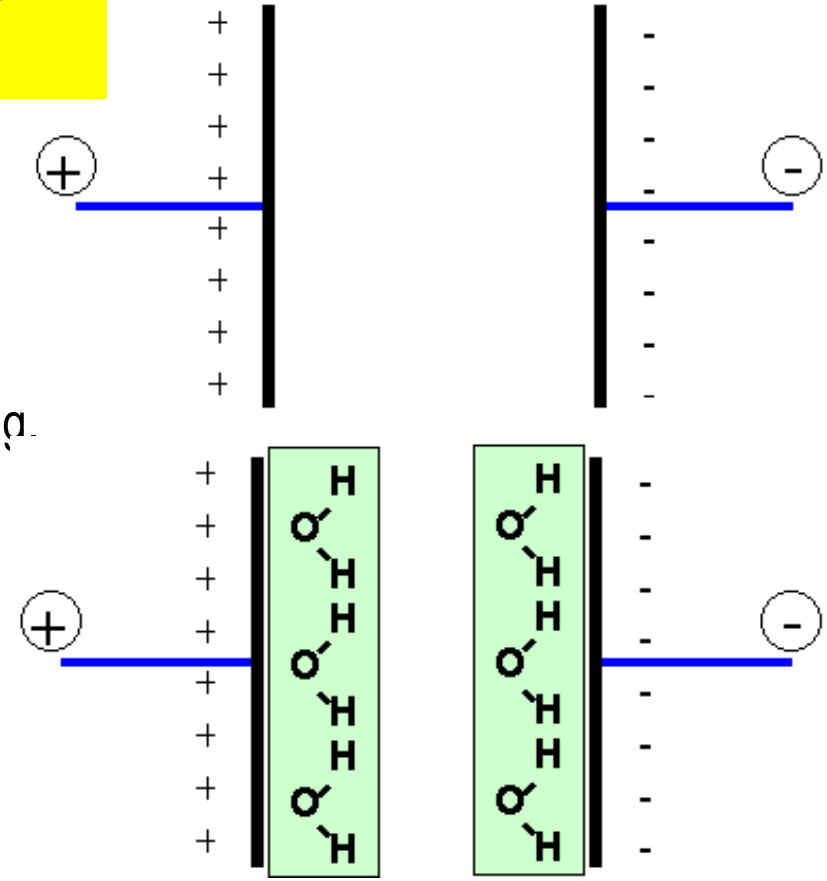
Polarization Vector, P

Electric Dipole Moment (- to +)

$$P = qd$$

$$P = Zqd$$





The process of dipole alignment is called ***Polarization***

Surface charge density or Dielectric Displacement:

D (C/m²) $\propto E_o$ (electric field V/m)

D = εE_o D = dielectric displacement

In the presence of an electric field, a force will tend to orient the electric dipole with the applied field

Example (Electronic Polarization)

Suppose that the average displacement of electrons relative to the nucleus in a copper atom is 1×10^{-8} Angstroms when an electric field is imposed on a copper plate. Calculate the electronic polarization. Data: Copper (Z=29 and lattice parameter = 3.6151 Angstroms)

Solution

$$Z = \frac{(4 atoms/cell)(29 electrons/atom)}{(3.6151)^3} = 2.46 \times 10^{30} electrons/m^3$$

Where **Z** is the number of electrons (electronic polarization) per unit volume

$$P = Z \times q \times d$$

$$P = (2.46 \times 10^{30} electrons/m^3)(1.6 \times 10^{-19} C/electron)(10^{-8} Angstroms)(10^{-10} m/Angstrom)$$

$$P = 3.94 \times 10^{-7} C/m^2$$

Example (Ionic Polarization)

Calculate the increase in separation of Cs^{+1} and Cl^{-1} in a **CsCl** crystal when an ionic polarization of $4x10^{-8}C.m^{-2}$ is achieved by the application of an electric field. Data: lattice parameter **a=0.402nm**, ionic radii **0.165nm** for Cs^{+1} and **0.181nm** for Cl^{-1}.

Solution

Use the equation $$P = Z \times q \times d$$

Where **Z** is the number of charges per unit volume i.e. (dipoles per cell) x (charges per cell) per unit volume

$$Z = \frac{(1 dipole_per_cell)(1_charge_per_dipole)}{(0.402 \times 10^{-9})^3 m^3_per_cell}$$

$$Z = 1.54 \times 10^{28} charges.m^{-3}$$

$$d = \frac{P}{Z \times q} = \frac{4 \times 10^{-8} C.m^{-2}}{(1.54 \times 10^{28} charges.m^{-3}) \times (1.6 \times 10^{-19} C/charge)}$$

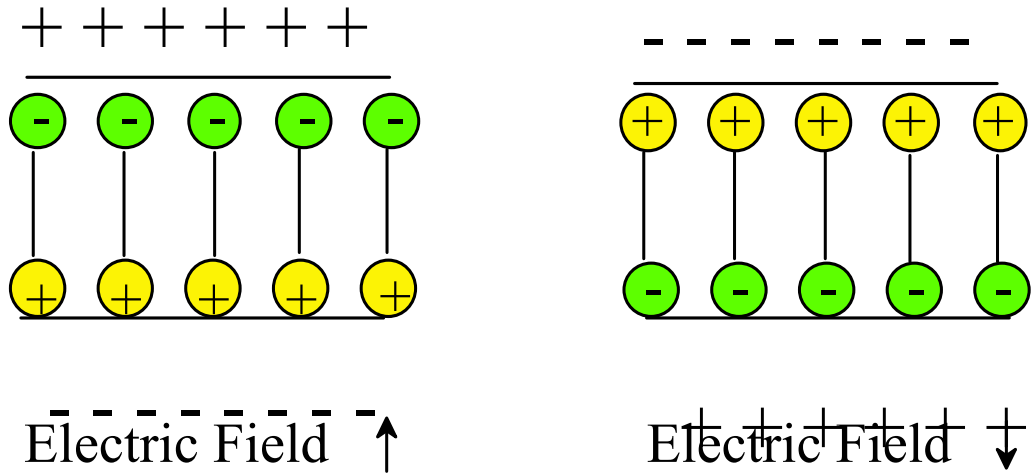
$$d = 1.62 \times 10^{-17} m = 1.62 \times 10^{-8} nm$$

Frequency Dependence of the Dielectric Constant

Alternating Current. (Applied voltage or electric field changes direction with time)

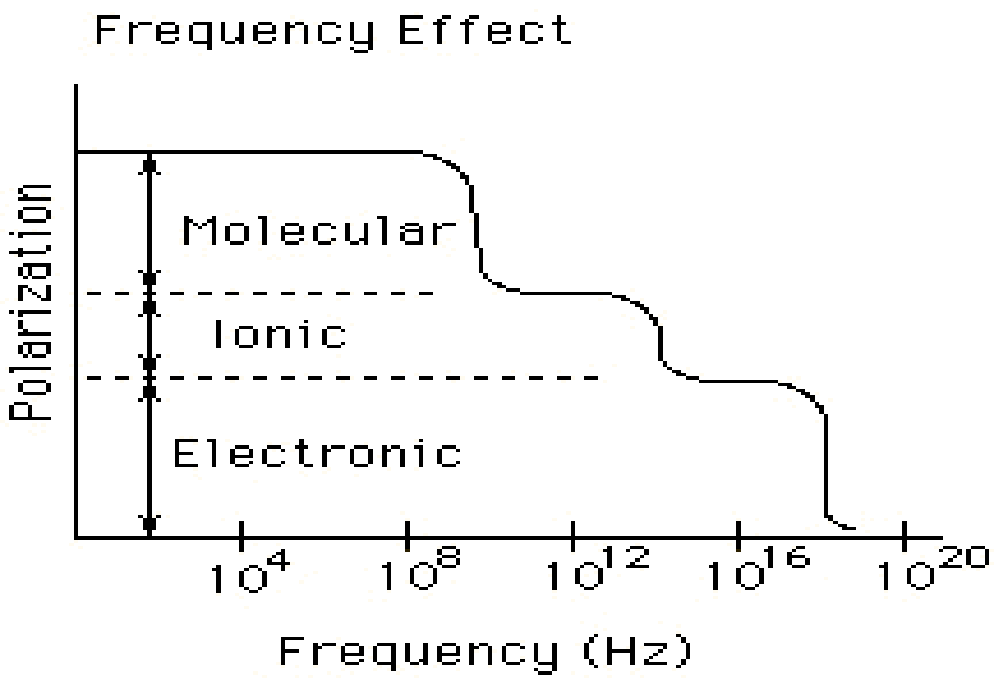
Dipoles try to reorient with field. (This requires time)

Relaxation Frequency = 1/time to reorient



Sometime dipoles can't keep up with changing electric field:

As frequency increases, dielectric constant decreases as orientation and ionic components go to zero.



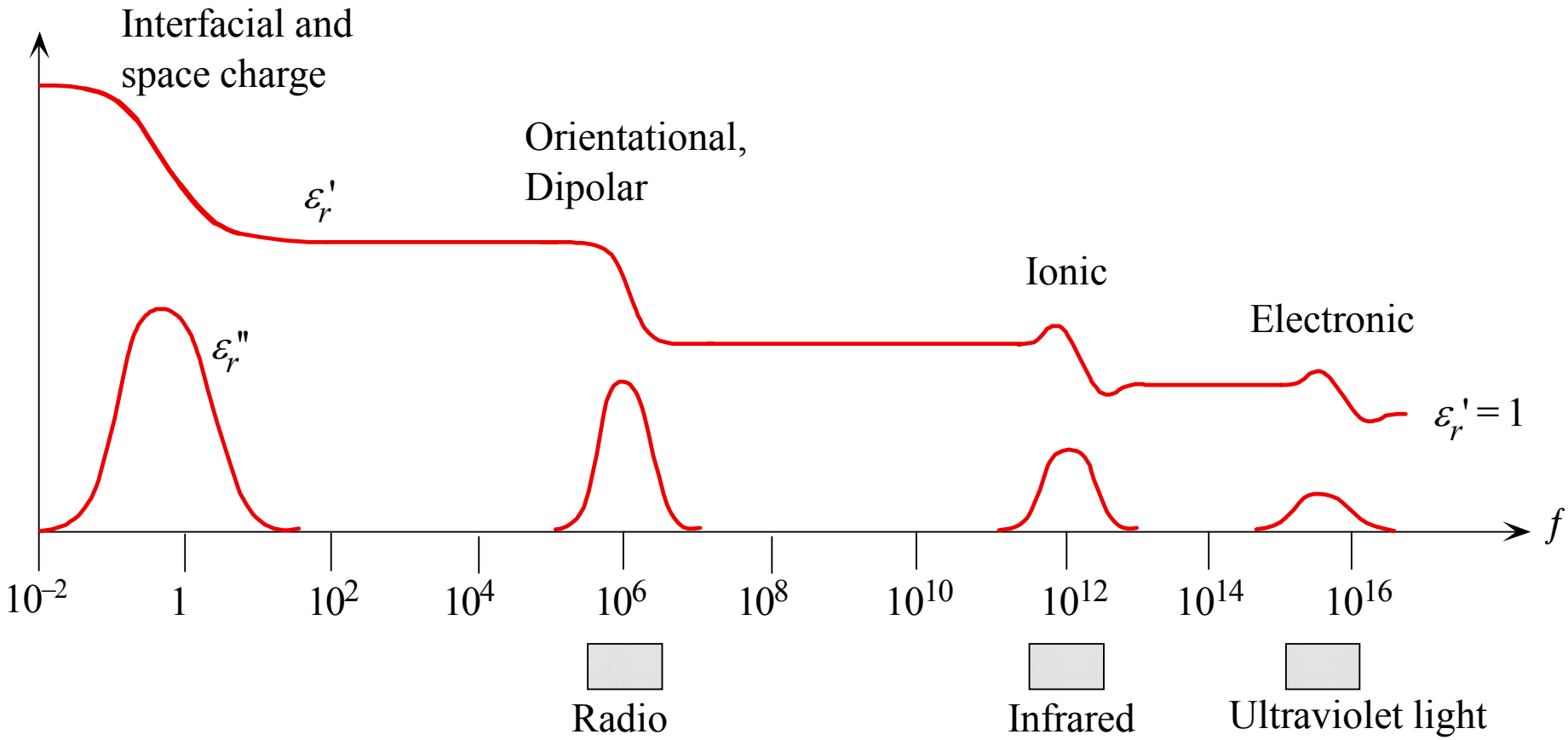


Fig. 7.14: The frequency dependence of the real and imaginary parts of the dielectric constant in the presence of interfacial, orientational, ionic and electronic polarization mechanisms.

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Table 19.4 Dielectric Constants and Strengths for Some Dielectric Materials

Material	*Dielectric Constant*		*Dielectric Strength (V/mil)*[a]
	60 Hz	*1 MHz*	
		Ceramics	
Titanate ceramics	—	15–10,000	50–300
Mica	—	5.4–8.7	1000–2000
Steatite (MgO–SiO_2)	—	5.5–7.5	200–350
Soda–lime glass	6.9	6.9	250
Porcelain	6.0	6.0	40–400
Fused silica	4.0	3.8	250
		Polymers	
Phenol-formaldehyde	5.3	4.8	300–400
Nylon 6,6	4.0	3.6	400
Polystyrene	2.6	2.6	500–700
Polyethylene	2.3	2.3	450–500
Polytetrafluoroethylene	2.1	2.1	400–500

[a] One mil = 0.001 in. These values of dielectric strength are average ones, the magnitude being dependent on specimen thickness and geometry, as well as the rate of application and duration of the applied electric field.

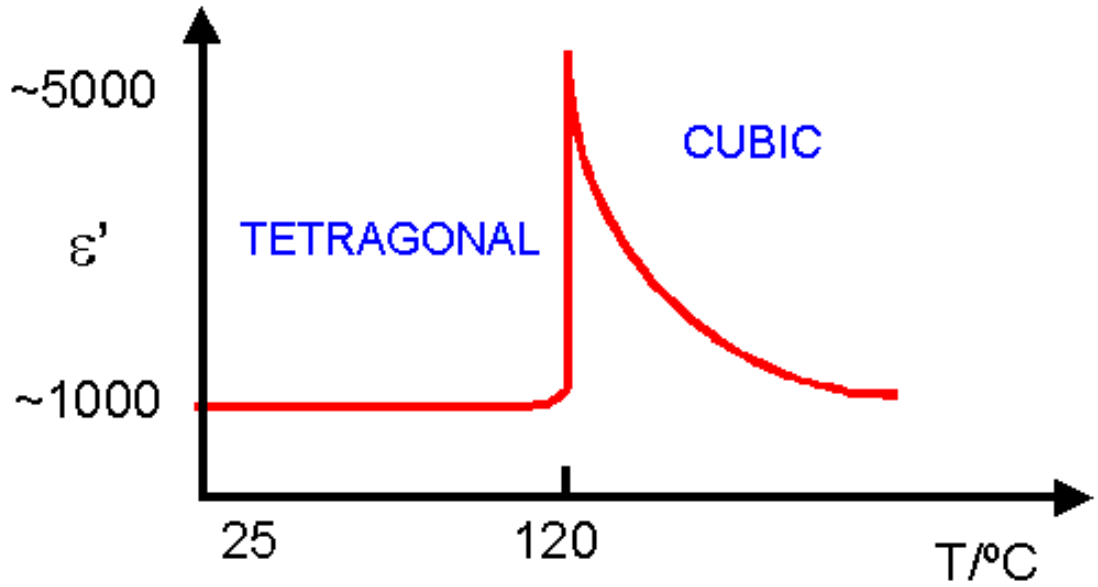
Define the permittivity or dielectric constant of a material by: $\varepsilon_r = \frac{Q}{Q_{vac}}$

H_2O is a polar liquid; $\varepsilon_r \sim 80$

Typical ionic solids; $\varepsilon_r \sim 10$

Air; $\varepsilon_r \sim 1$

$BaTiO_3$:-

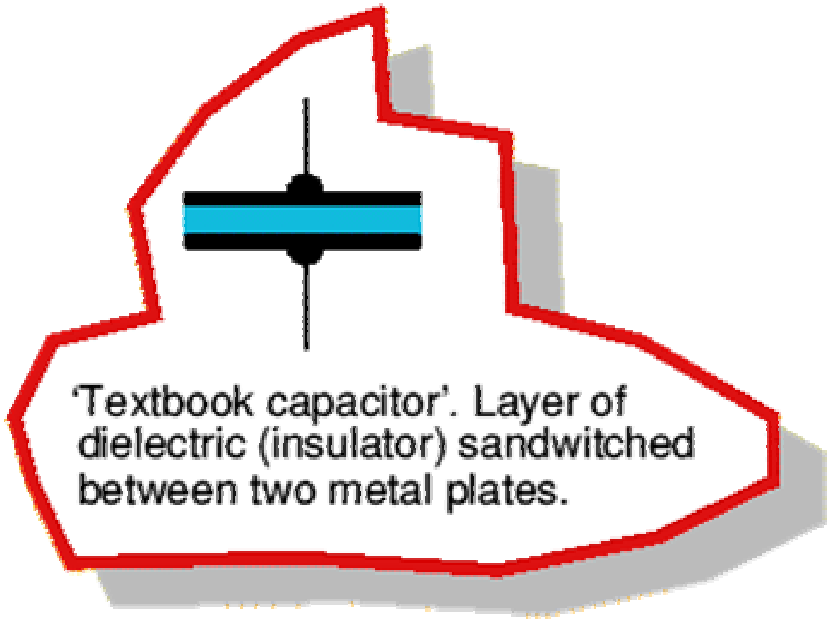


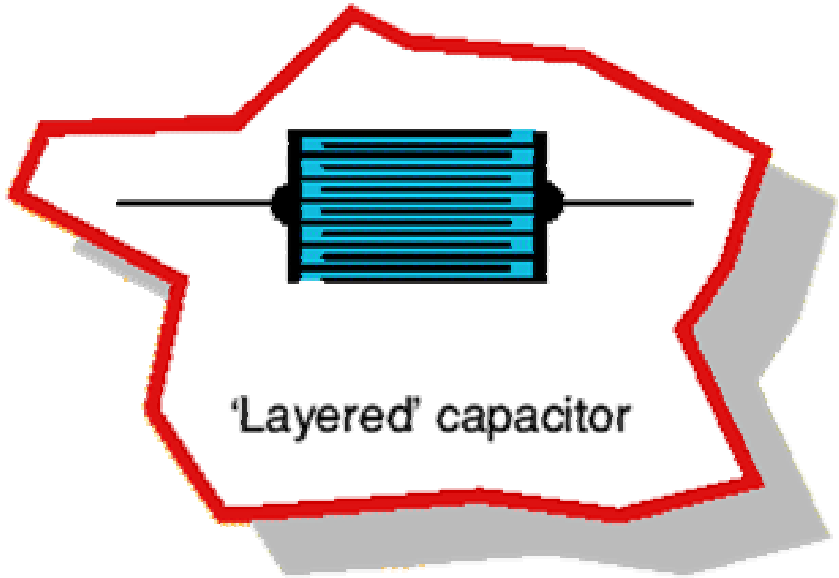
Below 120°C, $BaTiO_3$ is ferroelectric with aligned dipoles.

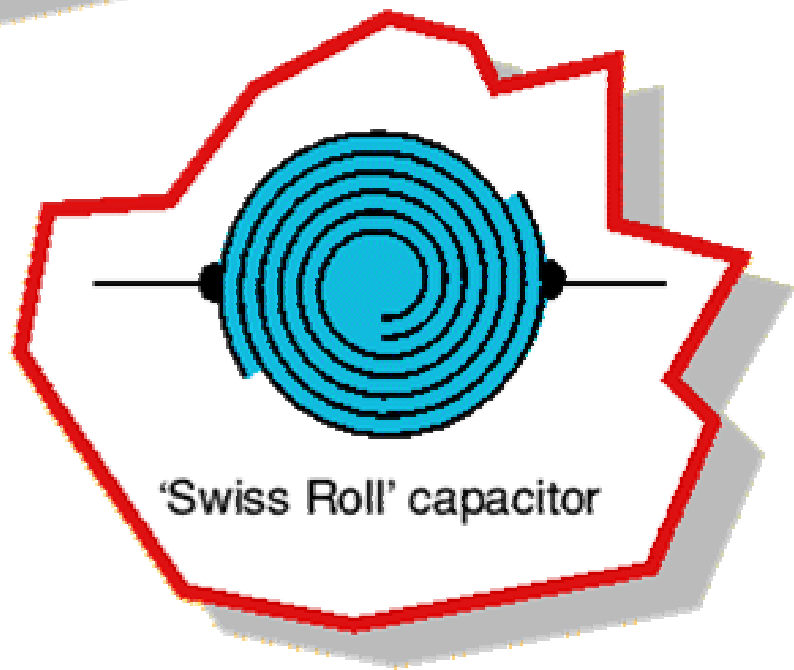
Residual dipole disorder gives ε_r~200-1000

At ~127°C, tetragonal $\rightarrow$ cubic phase transition.

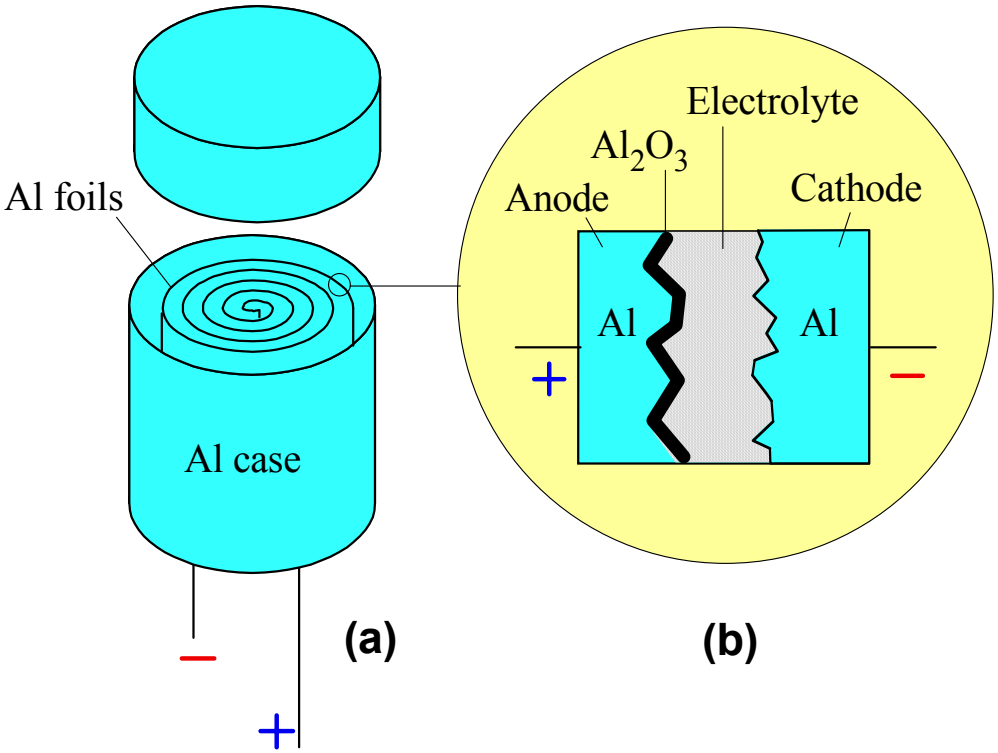
Dipoles randomise and ε_r increases to ~5,000-10,000


'Textbook capacitor'. Layer of dielectric (insulator) sandwitched between two metal plates.


'Layered' capacitor


'Swiss Roll' capacitor





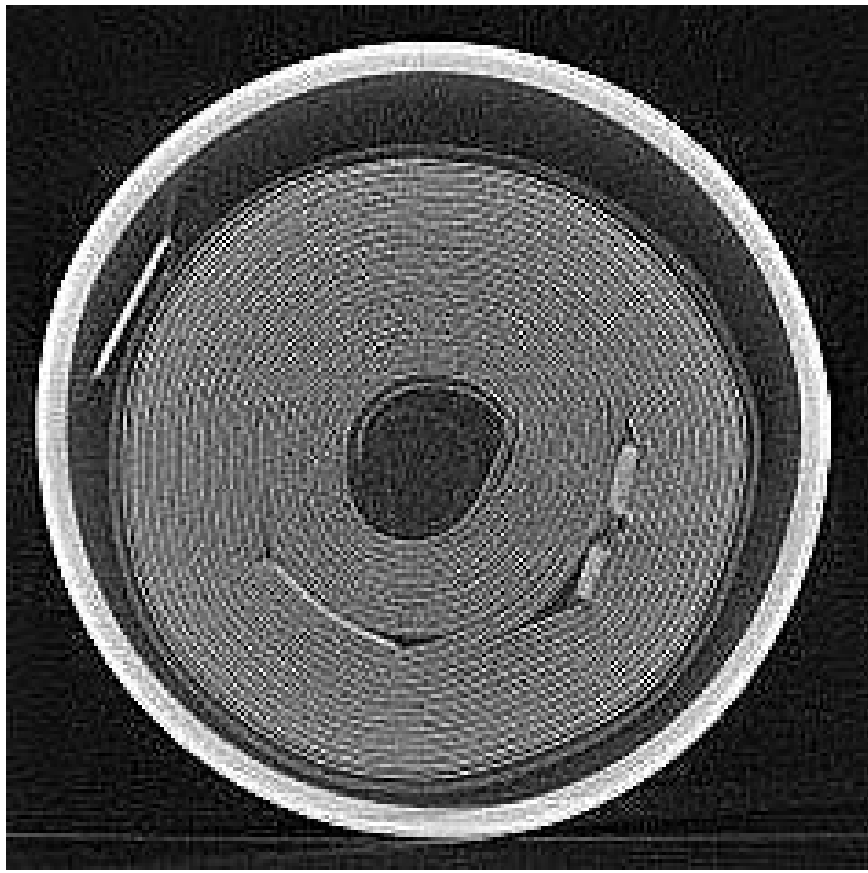


Fig. 7.31: Al electrolytic capacitor.

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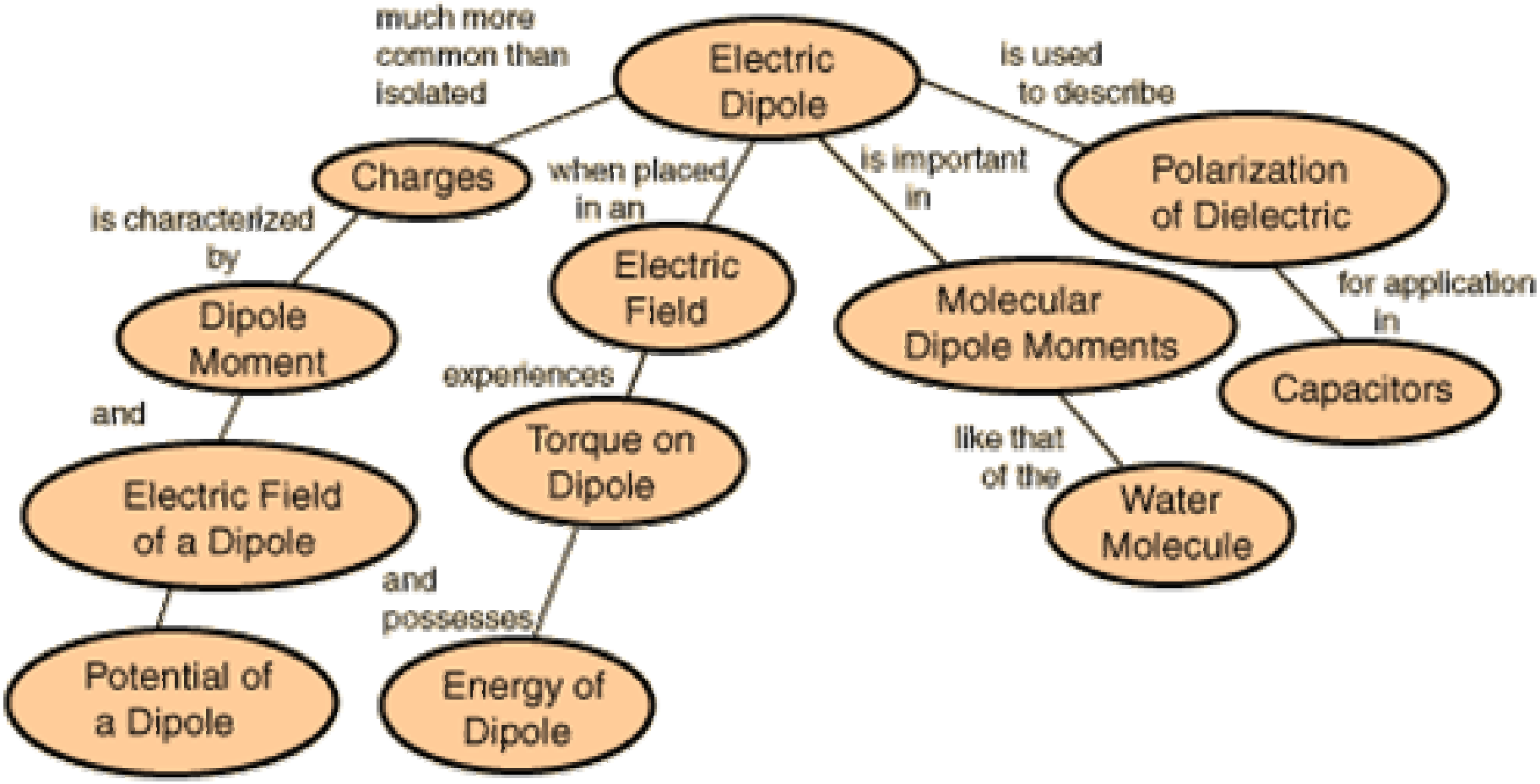
Example

A 2mm thick porcelain dielectric is used in a 60 Hz circuit. Calculate the voltage required to produce a polarization of 5×10^{-7} C.m^{-2}. Use Table.

Solution

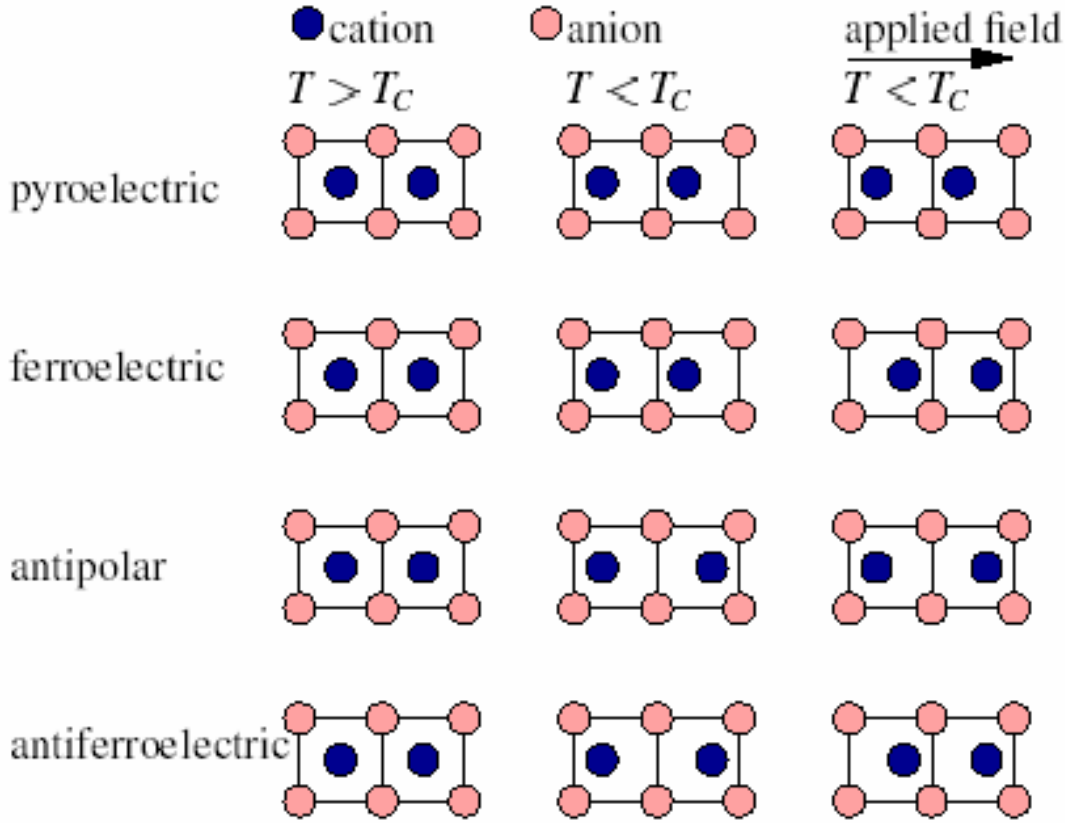
$$P = E_0 \varepsilon_0 \left(\varepsilon_r - 1 \right) = (6-1) \times 8.85 \times 10^{-12} \times \frac{V}{2 \times 10^{-3} m} = 5 \times 10^{-7}$$

$$V = 22.6 volts$$


Electric Dipole
much more common than isolated
Charges
is used to describe
Polarization of Dielectric
when placed in an
Electric Field
is important in
Molecular Dipole Moments
for application in
Capacitors
is characterized by
Dipole Moment
experiences
Torque on Dipole
and
Electric Field of a Dipole
like that of the
Water Molecule
and possesses
Potential of a Dipole
Energy of Dipole

Polar Materials

Solid with a natural charge separation even in the absence of a field



OVERVIEW: The properties of ferroelectricity, piezoelectricity, and pyroelectricity are determined by the crystal structure of a material.

Ferromagnetic materials possess a natural electric polarization.

Piezoelectricity refers to property that the polarization (or electric field) can be changed by mechanical perturbation of the structure.

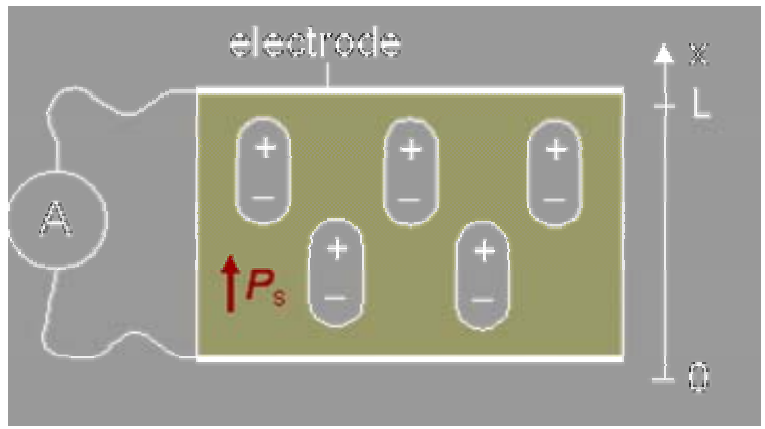
Pyroelectricity refers to the change in polarization by changes to structure from thermal effects.

All ferroelectric materials are piezoelectric, but not all piezoelectric materials are pyroelectric.

• Piezoelectric materials: There is coupling between electrical and mechanical energies. For example, an applied stress results in the generation of polarization.
• Pyroelectric materials: A material with a temperature dependent polarization. This requires a unique polar axis.
• Ferroelectrics: A subgroup of pyroelectric materials in which the spontaneous polarization can be reoriented between "equilibrium" states by applying an electric field. All ferroelectrics are both pyroelectric and piezoelectric.
• The possibility of inorganic crystals being polar (pyroelectric or piezoelectric) is strictly a function of their structure (point group symmetry)

Pyroelectricity

It is a property of dielectric materials, which show a temperature-dependent, macroscopic (permanent or spontaneous) polarization ***P***, i.e. they generate surface charges as a result of a temperature change Δ**T(t)**. These charges can either be detected directly or as a pyroelectric current **I(t)**.



Ferroelectric Materials

Dielectric materials that, by virtue of their crystal structure exhibit reversible and spontaneous dielectric polarization (polarization in the absence of an electric field).

Dielectric analogue of ferromagnetic materials (display permanent magnetic behavior).

There must exist in the material permanent electric dipoles.

Example: Barium Titanate

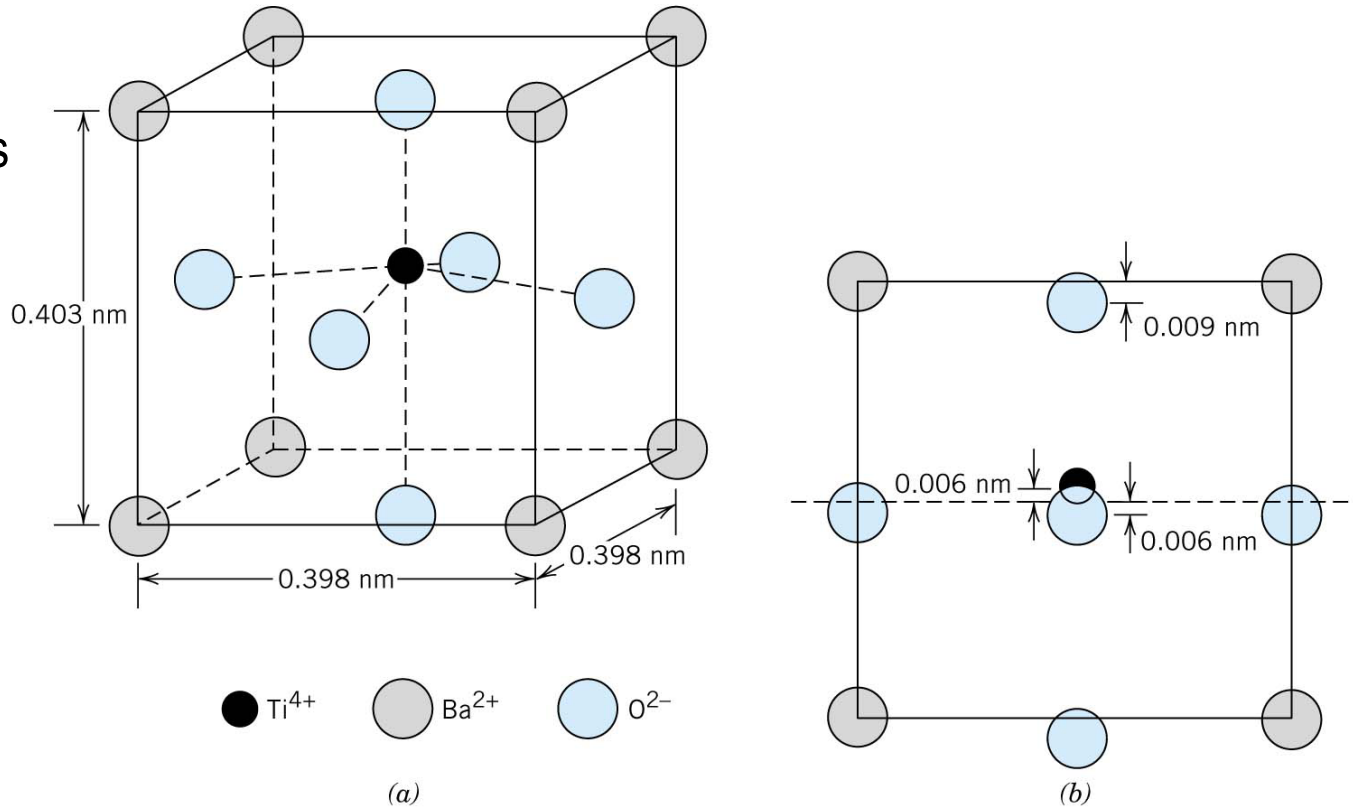
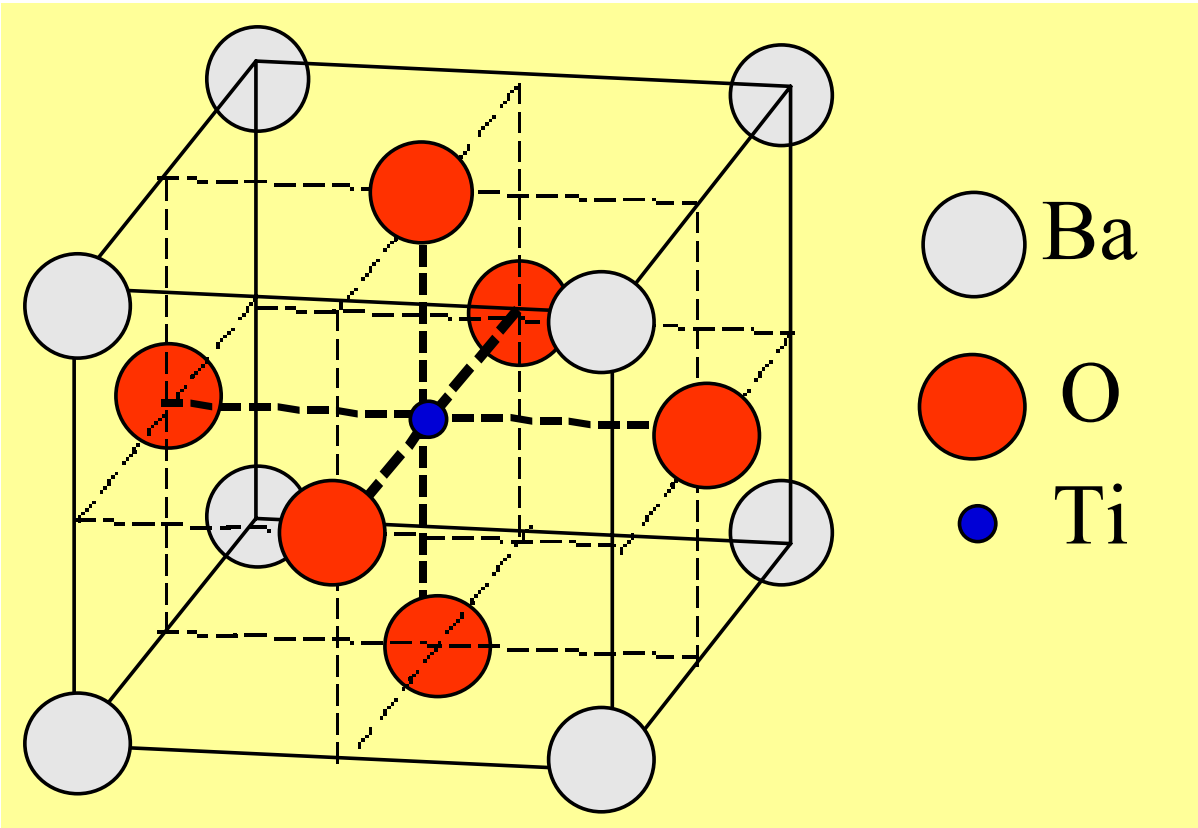


FIGURE 18.26 A barium titanate ($BaTiO_3$) unit cell (*a*) in an isometric projection, and (*b*) looking at one face, which shows the displacements of Ti^{4+} and O^{2-} ions from the center of the face.

Barium titanate has a tetragonal structure with a Ti^{4+} atom at the center. The dipole moment results from the relative displacement of the O^{2-} and Ti^{4+} ions from their symmetrical position. Thus, a permanent ionic dipole moment is associated with each unit cell.

However, when barium titanate is heated above its ferroelectric curie temperature (120°C), the unit cell becomes cubic, and all ions assume symmetric positions within the unit cell, the material now has a perovskite crystal structure and the ferroelectric behavior ceases.



Perovskite Crystal Structure ($A_mB_nX_p$)

Has interesting electromechanical properties

Other materials that display ferroelectricity:

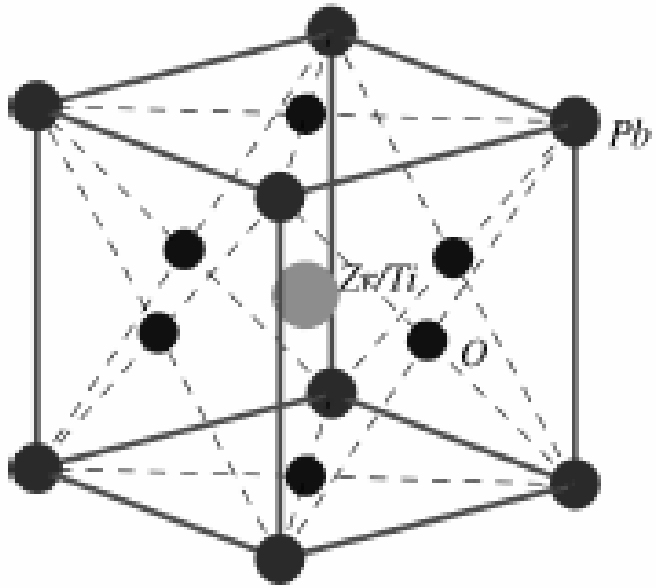
Rochelle Salt	$NaKC_4H_4O_6.4H_2O$
Potassium dihydrogen phosphate	KH_2PO_4
Potassium niobate	$KNbO_3$
Lead zirconate-titanate (PZT)	$Pb(ZrO_3,TiO_3)$

Ferroelectrics have extremely high dielectric constants at relatively low applied field frequencies; for example, at room temperature, ε_r for barium titanate may be as high as 5000. Consequently, capacitors made from these materials can be significantly smaller than capacitors made from other dielectric materials.

Analogous to ferromagnetic materials, ferroelectric materials have also ferroelectric domains and hysteresis. Ferroelectric domains are regions in the ferroelectric crystals that posses uniform polarization.

Perovskite: family name of a group materials having the same structure as the calcium titanate ($CaTiO_3$).

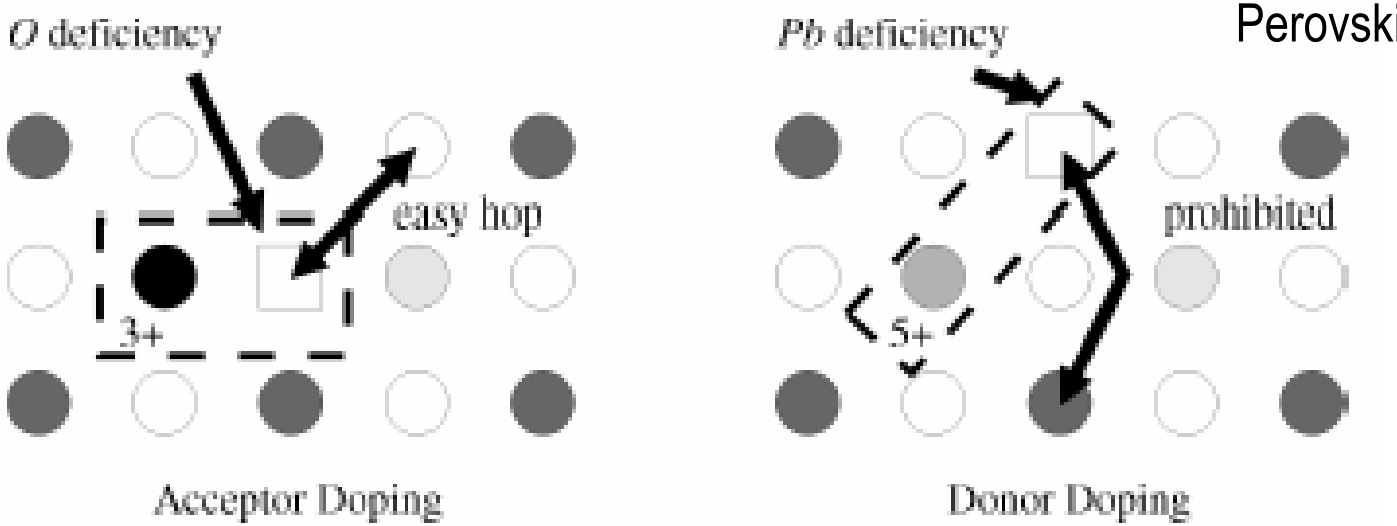
Barium Titanate ($BaTiO_3$), Lead Titanate ($PbTiO_3$), Lead Zirconate Titanate (PZT) and Lead Lanthanum Zirconate Titanate (PLZT)



Perovskite structure in PZT

Doping effect in PZT

PZT (Lead Zirconate Titanate) = $PbZrO_3 + PbTiO_3$



Acceptor ions (i.e. Fe^{3+}) introduce oxygen deficiencies (o). $Pb(Zr_yTi_{1-y}\text{-}xFe_x)(O_{3-x/2}o_{x/2})$

Donor ions (i.e. Nb^{5+}) introduce Pb deficiencies (•). $(Pb_{1-x/2}\ \bullet_{x/2})(Zr_yTi_{1-y-x}Nb_x)O_3$

Piezoelectricity

It means pressure-electricity. Unusual property of some ceramic materials, the application of external forces produces an electric (polarization) field and vice-versa.

Reversing the sign of the external force (from tension to compression) reverses the direction of the field.

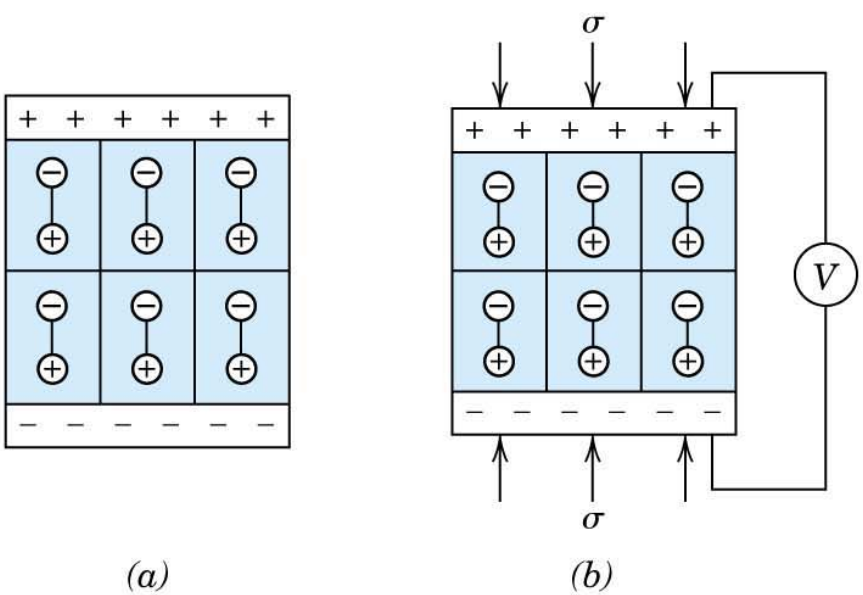
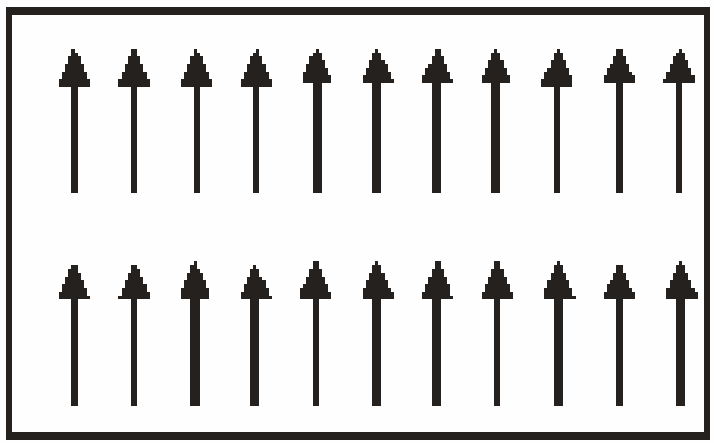


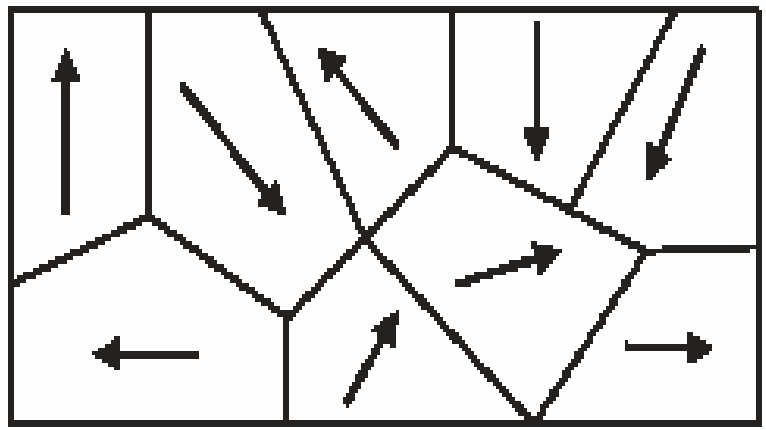
FIGURE 18.27 (*a*) Dipoles within a piezoelectric material. (*b*) A voltage is generated when the material is subjected to a compressive stress. (From *Elements of Materials Science and Engineering*, 6/E by Van Vlack, © Reprinted by permission of Pearson Education, Inc., Upper Saddle River, NJ.)

Piezoelectric effect basics

- Apply mechanical stress -> Electric charge produced
- Apply electric field -> Mechanical deformation produced
- Dipole: each molecule has a polarization, one end is more negatively charged and the other end is positively charged.
- Monocrystal: the polar axes of all of the dipoles lie in one direction. -- Symmetrical
- Polycrystal: there are different regions within the material that have a different polar axis. -- Asymmetrical

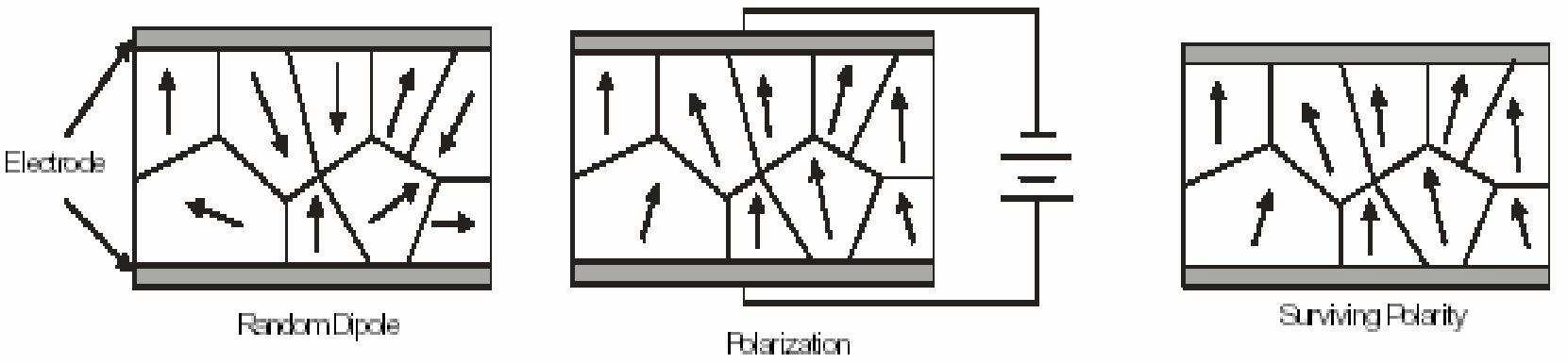


Monocrystal with single polar axis

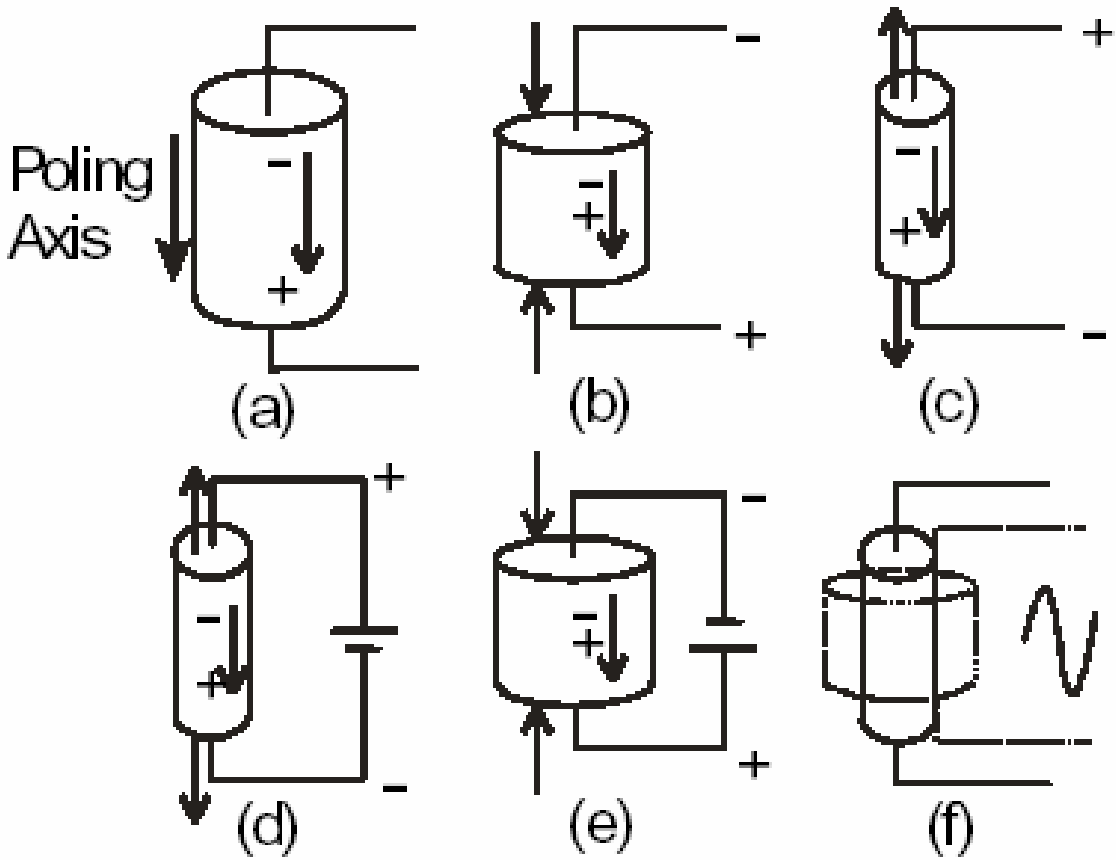


Polycrystal with random polar axis

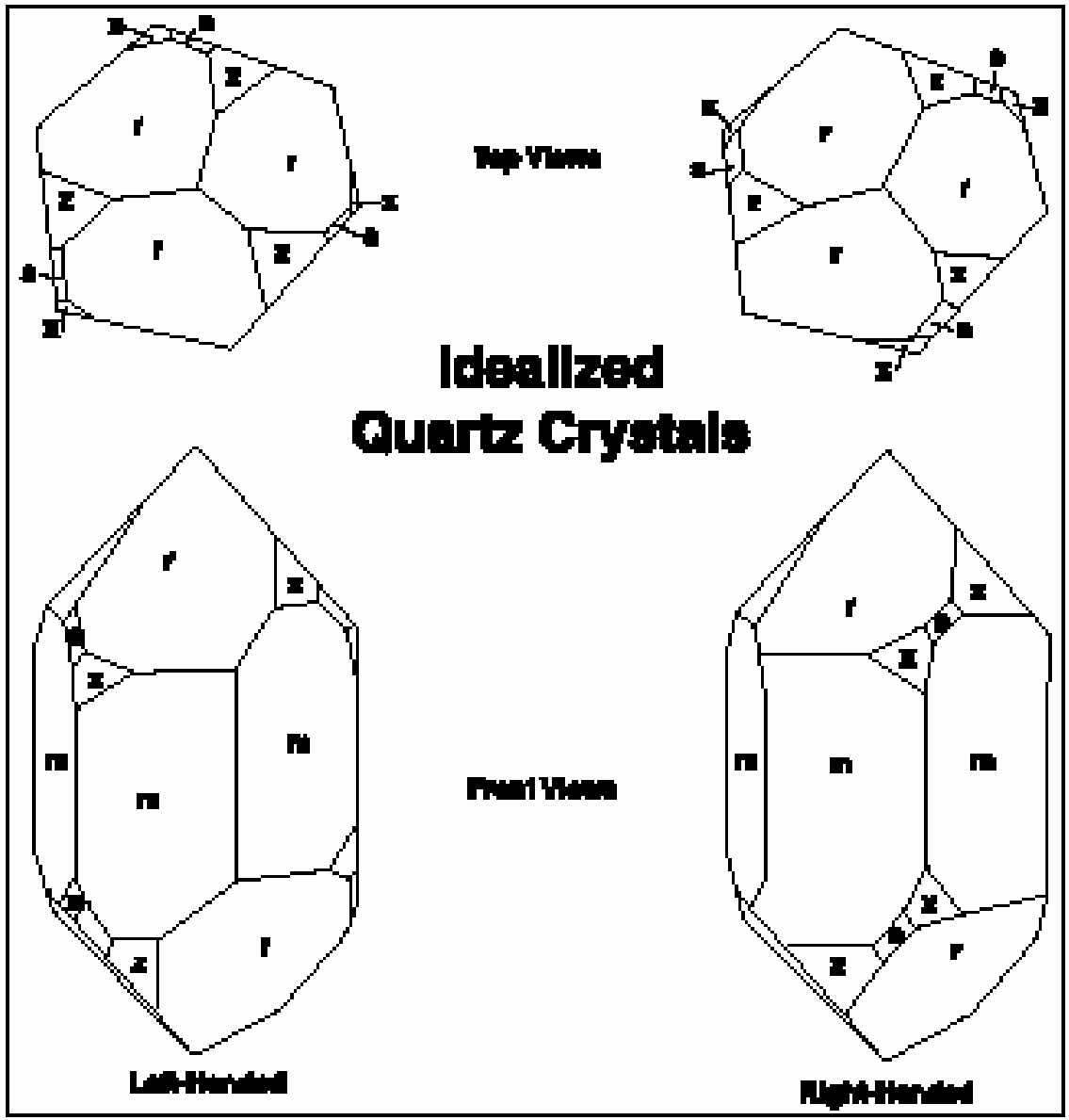
How to produce piezoelectric effect



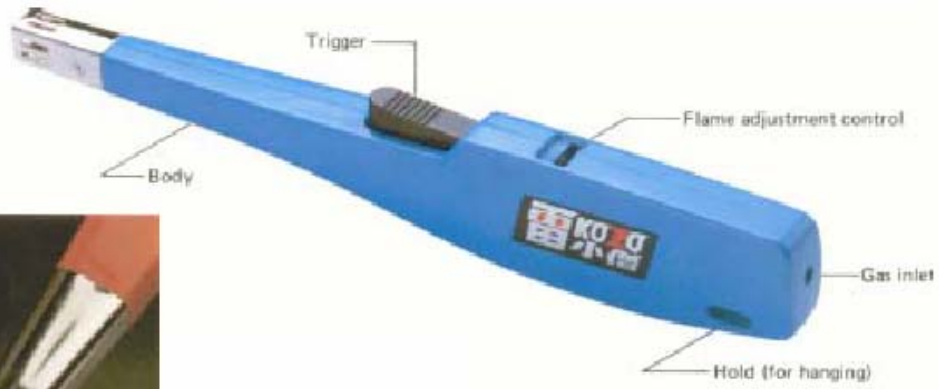
a) Material without stress / charge
b) Compress -> same polarity
c) Stretched -> opposite polarity
d) Opposite voltage -> expand
e) Same voltage -> compress
f) AC signal -> vibrate

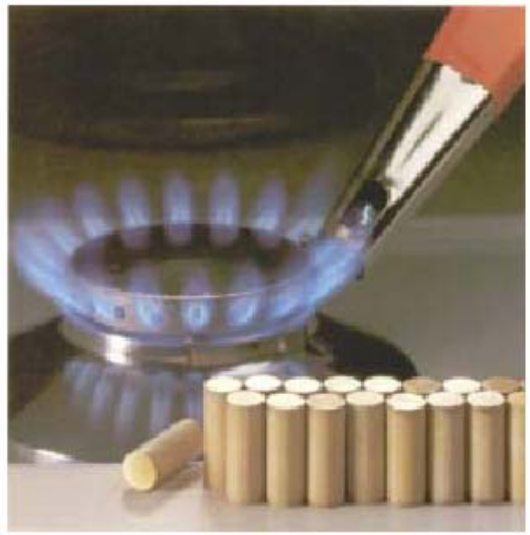


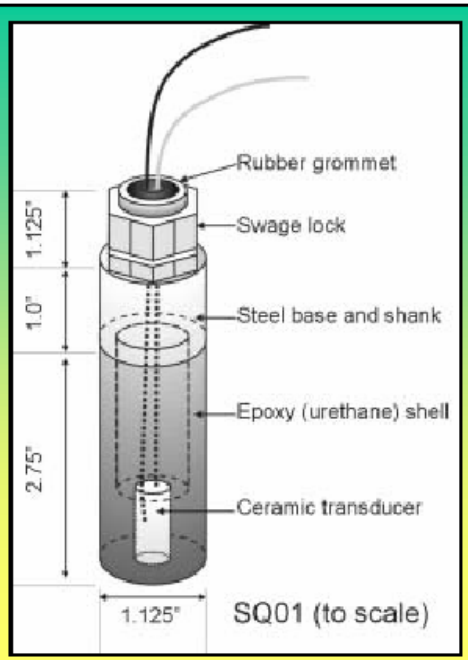
Applications of piezoelectric materials is based on conversion of mechanical strain into electricity (microphones, strain gauges, sonar detectors, audible alarms, ultrasonic imaging, speakers) Piezoelectric materials include barium titanate $BaTiO_3$, lead titanate, lead zirconate $PbZrO_3$, quartz, ammonium dihydrogen phosphate ($NH_4H_2PO_4$).

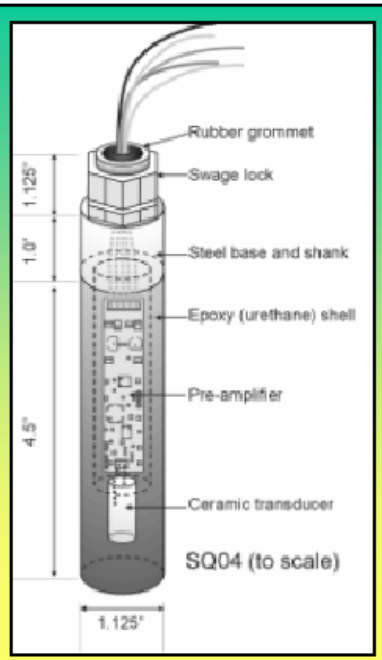


Piezoelectric Igniters



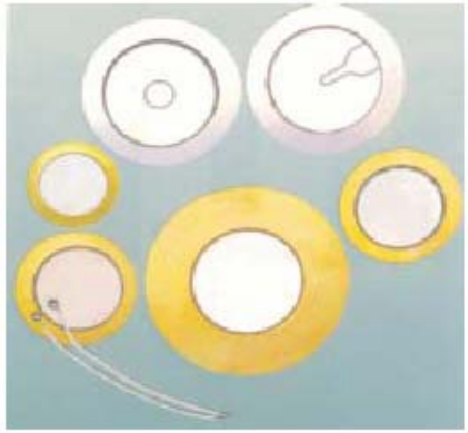






Hydrophones: A "Hydrophone" is a device which will listen to, or pick up, the acoustic energy underwater. A hydrophone converts acoustic energy into electrical energy and is used in passive underwater systems to listen only.

Piezoelectric
Audiotone
Transducers



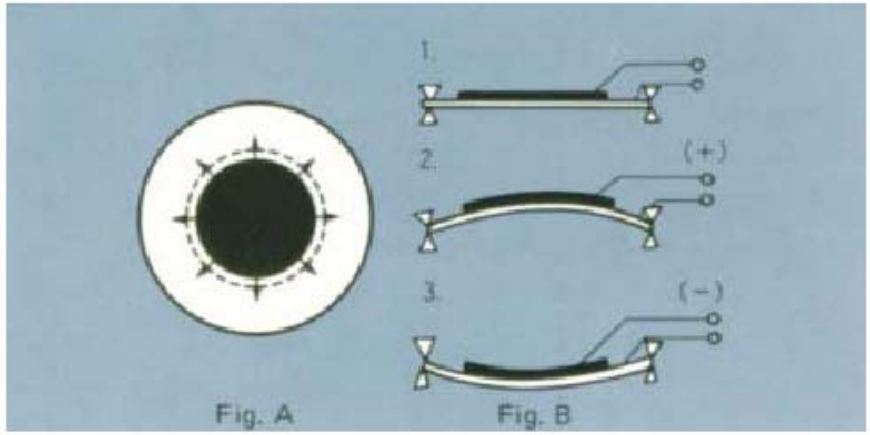
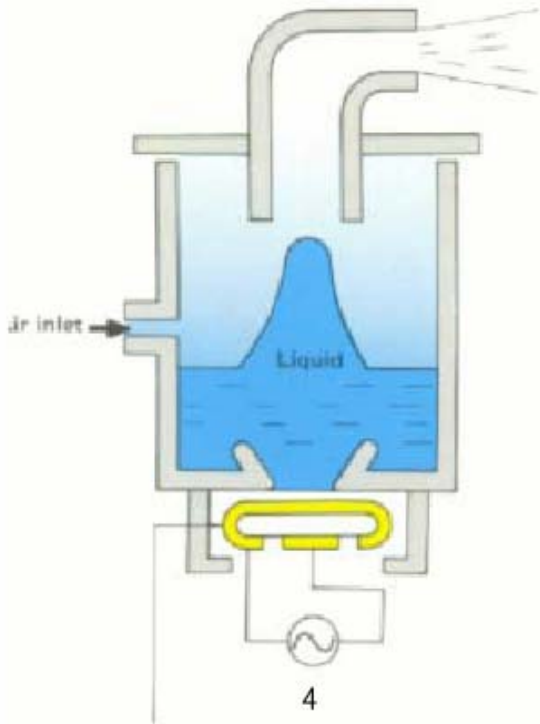


Figure A. Layered structure with ceramic bonded to metal diaphragm. Radial mode of vibration produces a bending effect.
Figure B. Alternating voltage produces convex and concave distortions in the diaphragm. Displacement of the diaphragm is in the order of microns.



1. Vibration; 2. Cavitation; 3. Misting
4. Ultrasonic Humidifier.



Liquid
Atomization
Devices

Example (Piezoelectric)

The piezoelectric spark generator as used in various applications such as lighters and car ignitions, operates by stressing a piezoelectric crystal to generate a high voltage which is discharge through a spark gap in air (see figure below).

The breakdown field for air is $3 \times 10^6 V.m^{-1}$. If you consider a gap of 1mm it is about 3000V.

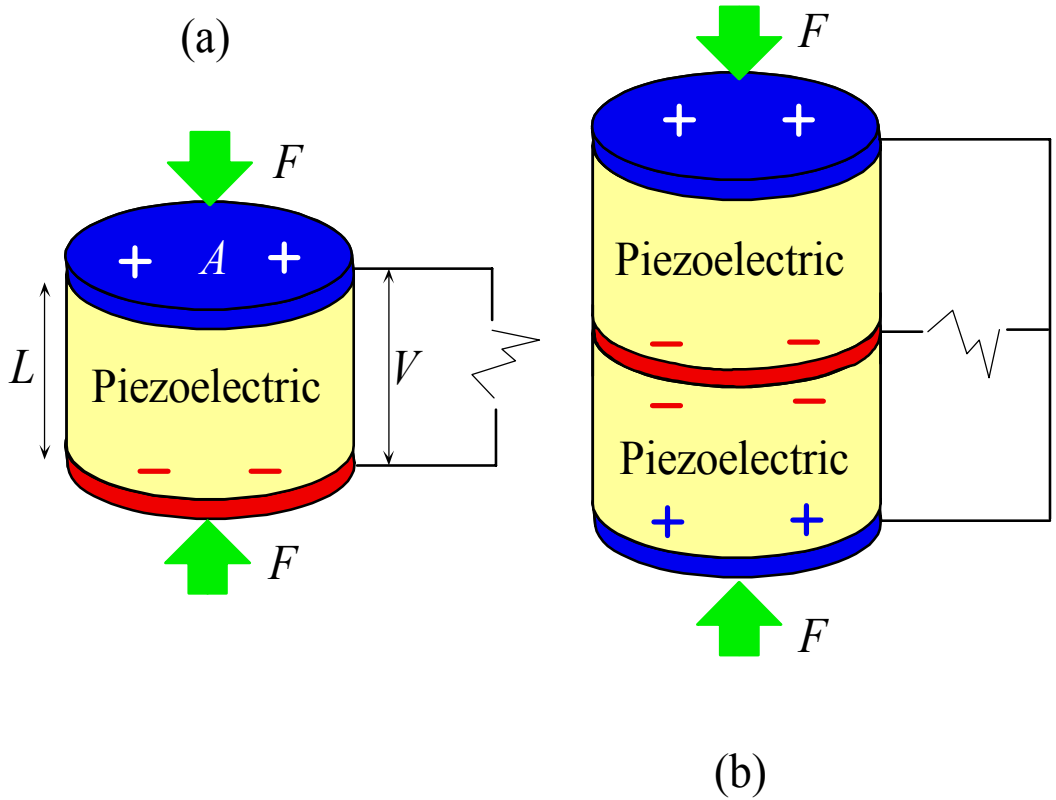


Fig. 7.39: The piezoelectric spark generator

From *Principles of Electronic Materials and Devices, Second Edition*, S.O. Kasap (© McGraw-Hill, 2002)
http://Materials.Usask.Ca

Additional Notes

The ratio of strain to electric field is called the ***"d"*** constant for a piezoelectric.

The ratio of voltage generated to stress applied is called the ***"g"*** constant (***piezoelectric voltage coefficient***) for a piezoelectric, where ***E(V/m)*** is the voltage ***ε*** is the strain , ***σ*** is the stress (Pa)

The ***"g"*** and ***"d"*** are related to the dielectric constant as follows: where ε_r is the dielectric constant and ε_0 is the permittivity under vacuum (8.85×10^{-12} F/m).

$$d = \frac{\varepsilon}{E} = \frac{strain}{electric_field_generated}$$

$$g = \frac{E}{\sigma} = \frac{electric_field_generated}{stress}$$

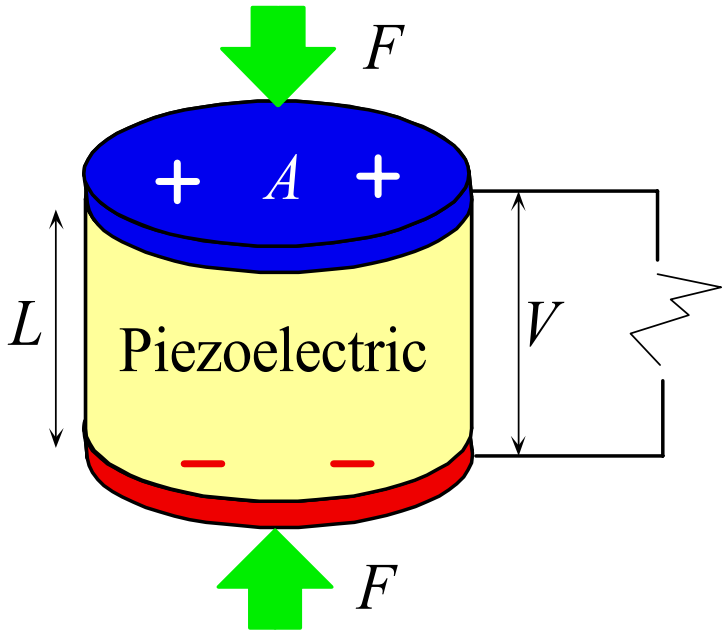
$$g = \frac{d}{\varepsilon_r \varepsilon_0}$$

Consider a piezoelectric sample in the form of a cylinder (see figure). Suppose that the piezoelectric coefficient ***d=250x10^{-12}m.V^{-1}*** and ε_r***=1000***.
The piezoelectric has a length of ***10mm*** and a diameter of ***3mm***. The spark gap is in air and has a breakdown voltage of about ***3.5kV***. What is the force required to spark the gap? Is this a realistic force?

Solution

$$g = \frac{d}{\varepsilon_r \varepsilon_0} = \frac{250\times10^{-12}\, m.V^{-1}}{(1000)\times(8.85\times10^{-12}\, F.m^{-1})}$$

$$g = 2.8\times10^{-2}\, m^2.(V.F)^{-1}$$



$$E = \frac{V}{L} = \frac{3500V}{0.01m} = 3.5\times10^{5} V.m^{-1}$$

$$g = \frac{E}{\sigma} \rightarrow \sigma = \frac{E}{g} = \frac{3.5 \times 10^{5} V.m^{-1}}{2.8 \times 10^{-2} (V.F)^{-1}.m^{2}}$$

$$\sigma = 1.25 \times 10^{7} V^{2}.F.m^{-3} = 1.25 \times 10^{7} N.m^{-2}$$

Farad = F units ($kg^{-1}\ m^{-2}\ s^{4}\ A^{2}$)

Volts=V units ($kg\ m^{2}\ s^{-3}\ A^{-1}$)

Newton=N units ($kg\ m\ s^{-2}$)

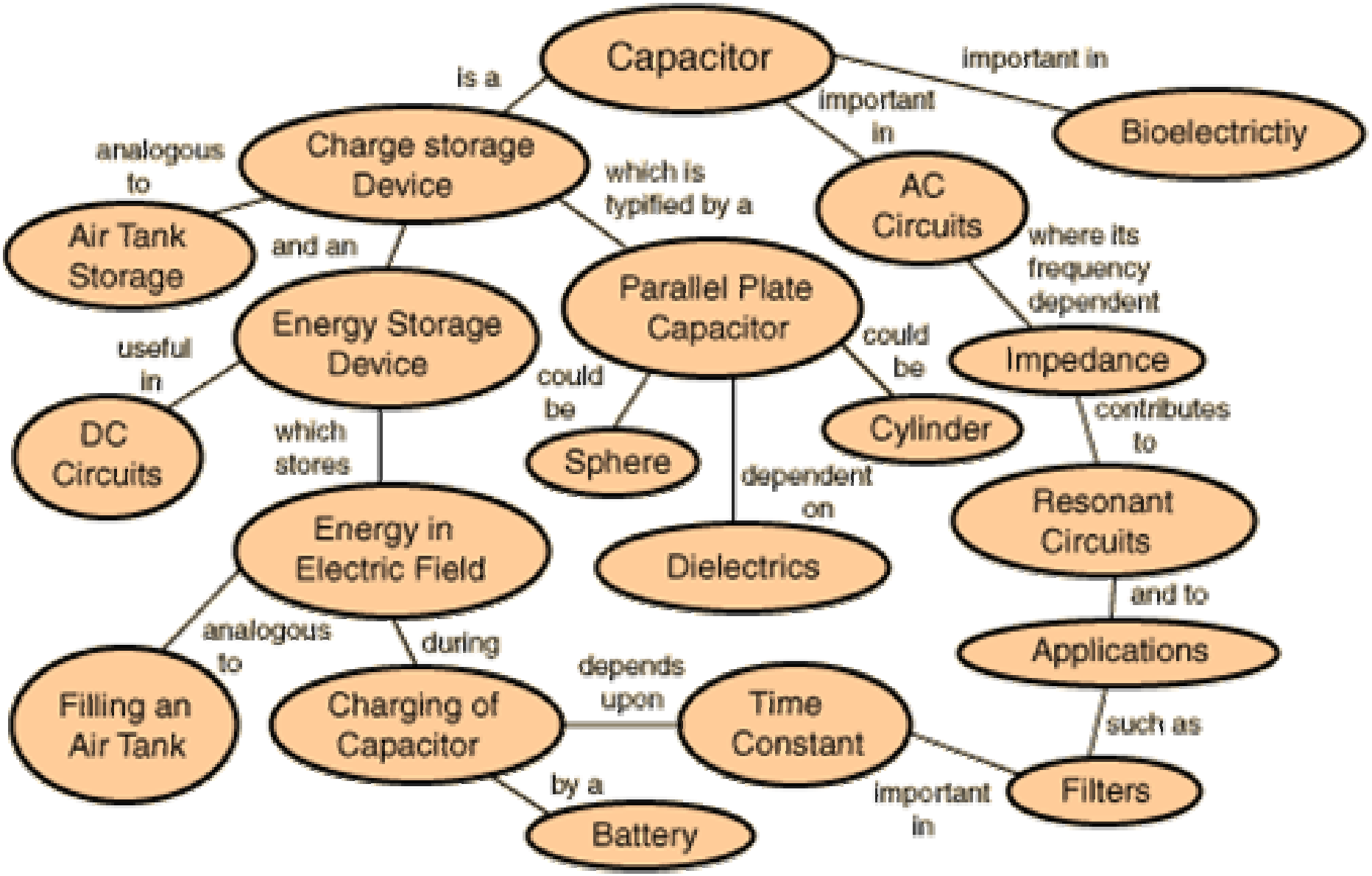
$$\sigma = \frac{Force}{Area} = \frac{F}{A} \rightarrow F = \sigma \times A = 1.25 \times 10^{7} \times \frac{\pi}{4} \times 0.003^{2}$$

$$F = 88.35N$$

This force (about 9kg) can be applied by squeezing by hand an appropriate lever arrangement.

The force must be applied quickly because the piezoelectric charge generated will leak away (become neutralized).

The voltage generated can be increased (or the force needed reduced) by using two piezoelectric crystals back to back.


Capacitor
is a
important in
Bioelectrictiy
important in
Charge storage Device
analogous to
Air Tank Storage
and an
which is typified by a
AC Circuits
where its frequency dependent
Energy Storage Device
Parallel Plate Capacitor
useful in
DC Circuits
could be
Sphere
could be
Cylinder
Impedance
contributes to
which stores
dependent on
Dielectrics
Resonant Circuits
Energy in Electric Field
and to
Applications
analogous to
Filling an Air Tank
during
depends upon
Charging of Capacitor
Time Constant
such as
Filters
by a
Battery
important in

CRYSTAL SYMMETRY:

Crystal structures can be divided into 32 classes, or point groups, according to the number of rotational axes and reflection planes they exhibit that leave the crystal structure unchanged. Twenty of the 32 crystal classes are piezoelectric. All 20 piezoelectric classes lack a center of symmetry. Any material develops a dielectric polarization when an electric field is applied, but a substance which has such a natural charge separation even in the absence of a field is called a polar material. Whether or not a material is polar is determined solely by its crystal structure. Only 10 of the 32 point groups are polar. Under normal circumstances, even polar materials do not display a net dipole moment. As a consequence there are no electric dipole equivalents of bar magnets because the intrinsic dipole moment is neutralized by "free" electric charge that builds up on the surface by internal conduction or from the ambient atmosphere. Polar crystals only reveal their nature when perturbed in some fashion that momentarily upsets the balance with the compensating surface charge.

PYROELECTRICITY:

Spontaneous polarization is temperature dependent, so a good perturbation probe is a change in temperature which induces a flow of charge to and from the surfaces. This is the pyroelectric effect. All polar crystals are pyroelectric, so the 10 polar crystal classes are sometimes referred to as the pyroelectric classes.

The property of pyroelectricity is the measured change in net polarization (a vector) proportional to a change in temperature. The total pyroelectric coefficient measured at constant stress is the sum of the pyroelectric coefficients at constant strain (primary pyroelectric effect) and the piezoelectric contribution from thermal expansion (secondary pyroelectric effect). Pyroelectric materials can be used as infrared and millimeter wavelength detectors.

FERROELECTRICITY:

Ferroelectrics are materials which possess an electric polarization in the absence of an externally applied electric field such that the polarization can be reversed if the electric field is reversed. Normally materials are very nearly electrically neutral on the macroscopic level. However, the positive and negative charges which make up the material are not necessarily distributed in a symmetric manner. If the sum of charge times distance for all elements of the basic cell does not equal zero the cell will have an electric dipole moment which is a vector quantity. The dipole moment per unit volume is defined as the dielectric polarization.

PIEZOELECTRIC EFFECT:

The piezoelectric effect is a linear, reversible electromechanical interaction occurring in materials possessing the proper symmetry properties. The direct piezoelectric effect is the production of an electric polarization by a strain; the converse piezoelectric effect is the production of a stress by an electric field. Piezoelectric materials have wide applications as transducers - transferring mechanical motion into electricity or electricity into mechanical motion. One of the most wide spread examples is a quartz resonator. The quartz resonator converts the electrical potential energy of a battery into a steady beat that becomes the oscillator (counter) of a watch.