Ultrasonic non destructive testing advance lecture

Guy Feuillard

ELyT school

Content

- Element of acoustic
- Few words on piezoelectricity
- US transducer.
- Applications:
  - Medicine
  - High temperature US characterization
  - Reverberation

Element of acoustic and piezoelectricty

ElyT School

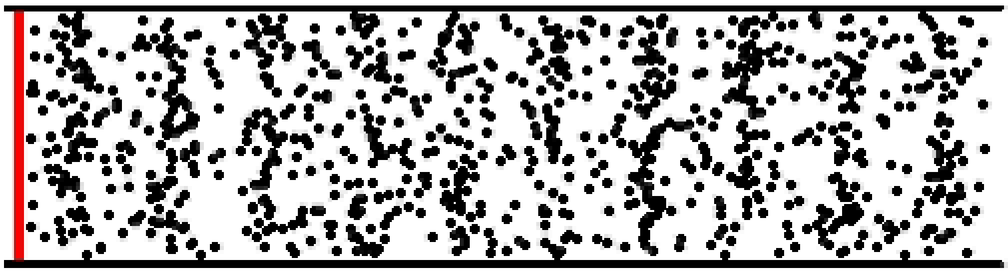
Guy Feuillard

- Outline
  - Acoustic waves in fluids
  - One dimensional acoustic waves
  - Fundamental laws of acoustics
  - Energy and acoustics
  - Transmission and reflexion

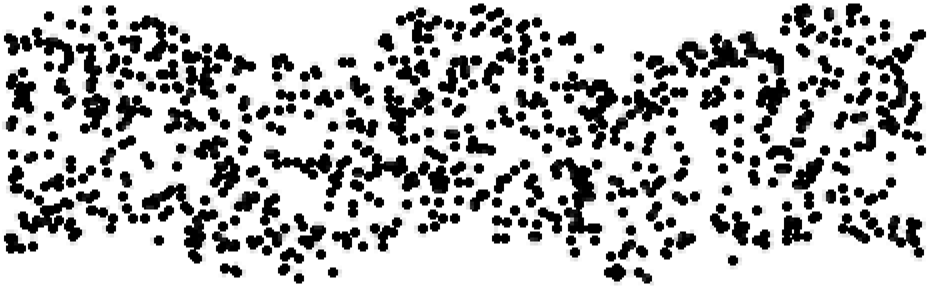
Acoustic waves

The wave vector $\vec{k} = \frac{\omega}{c}\mathbf{u}$

Bulk waves



Longitudinal waves :
Displacement // propagation
(fluids & solids)



Transverse waves
Displacement ⊥ propagation
(solids only)

Ultrasonic celerity

$$c = \sqrt{\frac{1}{\rho_0 \chi}}$$ In fluids

In solids

$$c_L = \sqrt{\frac{M}{\rho_0}}$$

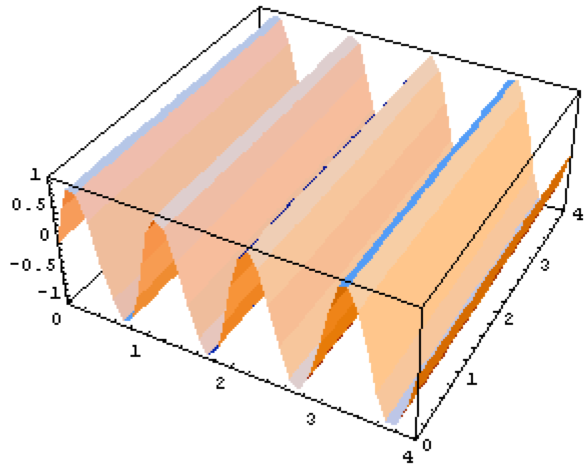
$$c_T = \sqrt{\frac{G}{\rho_0}}$$

$$M = K + \frac{4}{3}G$$

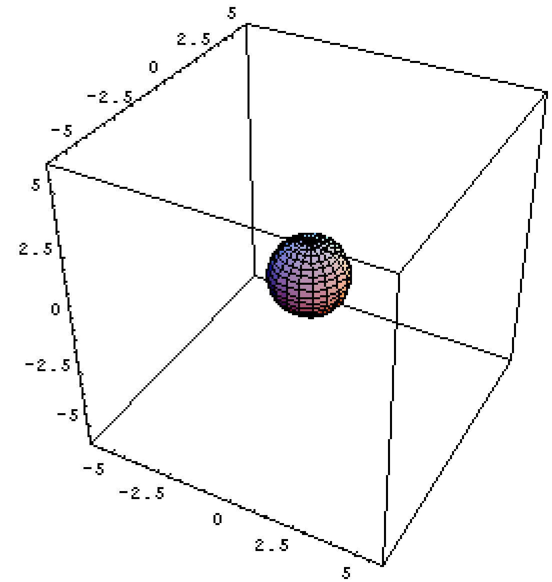
Material	Density [Kg/m3]	Longitudinal celerity [m/s]	Shear velocity [m/s]
Air (0 degree)	1,293	331	
Air (20 degree)	1,20	344	
Alcohol	790	1207	
Water (pure)	998	1480	
Aluminum	2790	6320	3130
Steel	7800	5900	3200

Waveform

Plane waves



Spherical waves



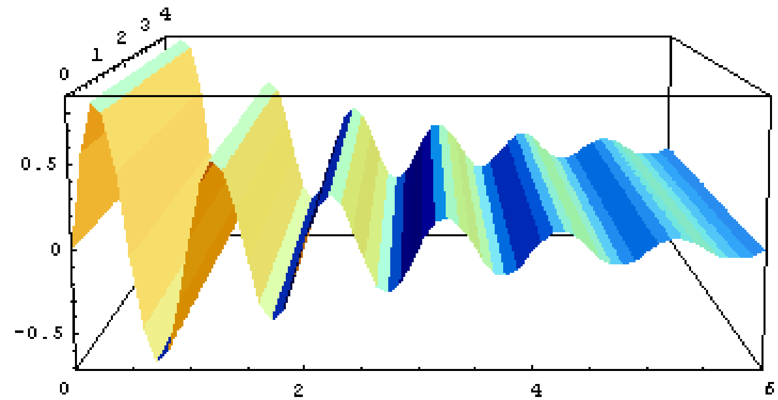
$$u_x = U_M \cos(\omega t - \frac{\omega}{c} x)$$

Attenuation: diffusion, viscosity

$$u_x = U_M e^{-\alpha x} \cos(\omega t - \frac{\omega}{c} x)$$

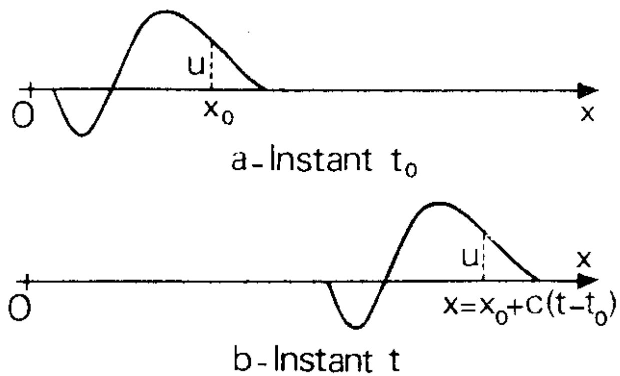
Attenuation factor

$$\alpha = 8.686 \times a\omega^2$$ dB/m



Water α= 0.22 dB/m @ 1MHz

Mathematical expression of a plane wave



Progression d'un ébranlement. Repéré par le niveau u au point x_0 et à l'instant t_0, l'ébranlement, se propageant à la vitesse c, atteint, à l'instant t, le point x tel que $x = x_0 + c(t - t_0)$.

$$x = x_0 + c(t - t_0)$$

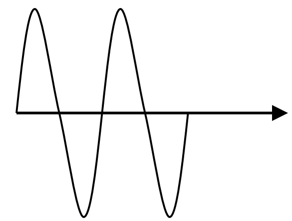
$$x - ct = x_0 - ct_0 \text{ ou } t - \frac{x}{c} = t_0 - \frac{x_0}{c}$$

$$u(x,t) = F(t - \frac{x}{c}) = f((x - ct)$$ Forward propagation x ↗

$$u(x,t) = G(t + \frac{x}{c}) = g((x + ct)$$ Backward propagation x ↘

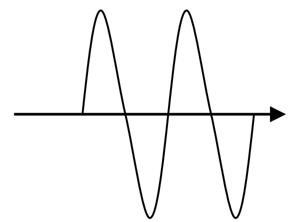
Acoustic wave generated @ x=0

$$u_M = A\cos\omega t \quad \text{with} \quad \omega = \frac{2\pi}{T}$$



At a position x

$$u(x,t) = A\cos\omega(t - \frac{x}{c})$$



Usefull parameters:

$$\lambda = cT = \frac{c}{f}$$ Wavelength

$$k = \frac{2\pi}{\lambda} = \frac{\omega}{c}$$ Wave number

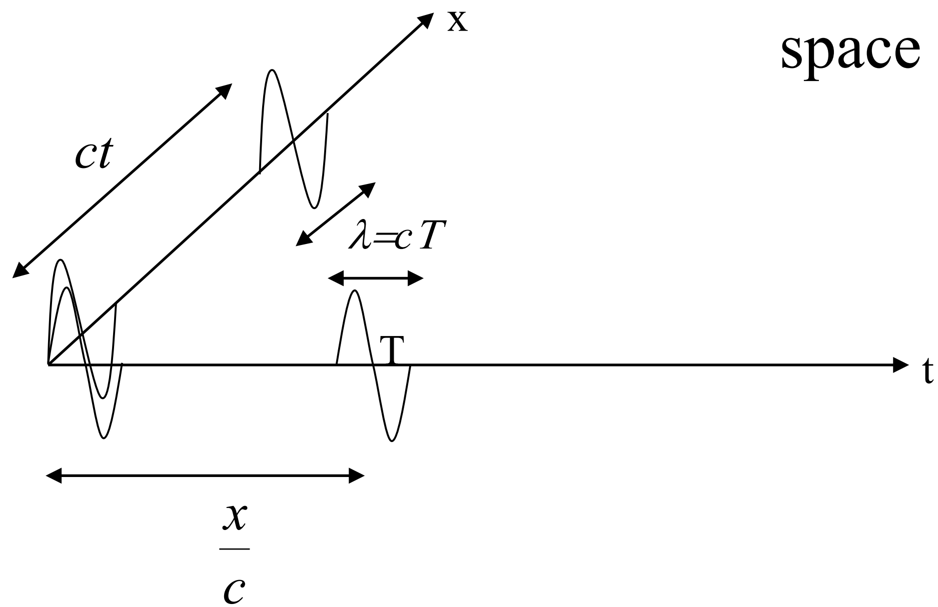
$$u = A\cos(\omega t - kx)$$

$$\varphi = \omega t - kx$$ Phase

Correspondance

Time

space



Complex notation

$$u_C = Ae^{j(\omega t-\phi)} \qquad v_C = Be^{j(\omega t-\psi)}$$

$$u = \Re e(u_C)$$

derivative

$$\frac{du_C}{dt} = j\omega u_C$$

$$\frac{du_C}{dx} = -jku_C$$

modulus

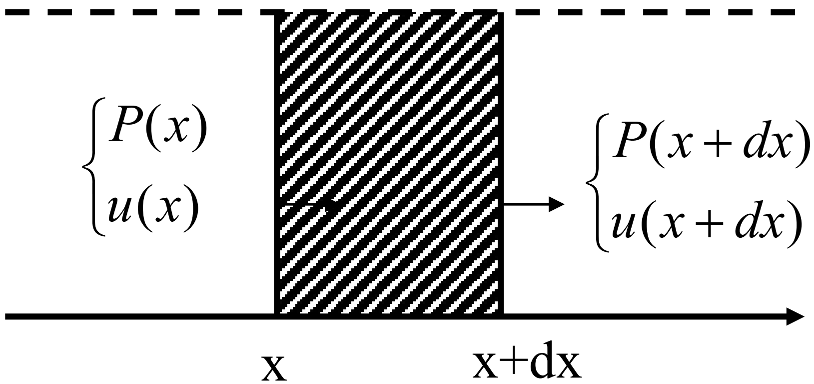
$$A^2 = u_C u_C^*$$

Mean value

$$\langle u(t)v(t)\rangle = \frac{1}{2}(u_C.v_C^*)$$

Exercice : demonstrate the relation above

One dimensional equations of acoustic



Fluide

u(x,t) displacement of a fluid slice

Dynamic equation $$dx\rho_0 \frac{\partial^2 u}{\partial t^2} = P(x) - P(x+dx)$$

$$P(x) - P(x+dx) = -dP = -\frac{\partial P}{\partial x} dx$$ =>

$$\boxed{\rho_0 \frac{\partial^2 u}{\partial t^2} = -\frac{\partial P}{\partial x}}$$

Relation between P and u ?

Pressure excess

Thermo says : the compressibility is $\chi = -\frac{1}{V}\frac{\partial V}{\partial P}$ hence $\partial P = -\frac{1}{\chi}\frac{\partial V}{V}$

If A is lateral surface

$$\partial V = A\left[u(x+dx) - u(x)\right]$$

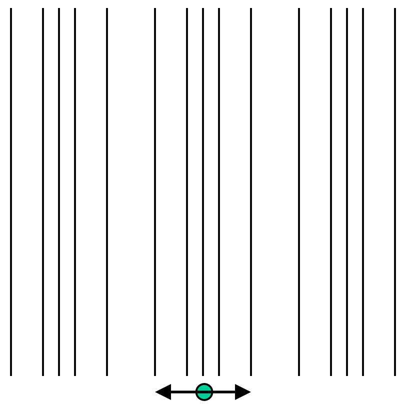
et $V = Adx$ ➡ $\frac{\partial V}{V} = \frac{\partial u}{\partial x}$ Local displacement

=> $$\boxed{\partial P = -\frac{1}{\chi}\frac{\partial u}{\partial x}}$$

➡ Wave equation $$\frac{\partial^2 u}{\partial t^2} = \frac{1}{\rho_0 \chi}\frac{\partial^2 u}{\partial x^2} = c^2 \frac{\partial^2 u}{\partial x^2}$$

with $c = \sqrt{\frac{1}{\rho_0 \chi}}$ Celerity of the acoustic wave

Fundamental laws wave propagation in a perfect, non turbulent fluid



$P, \dot{v}, \rho$

P, pressure

$\dot{v}$ Particle velocity

ρ, density

F an external force an q an acoustic source

Relations betweeen these 3 variables and the sources ?

Hypothesis : -small acoustic perturbations

-Adiabatic phenomenon

-

3 unknown 3 équations

Linear acoustic equations

$$P = c^2 \rho$$ State (1)

$$\rho_0 \frac{d\vec{v}}{dt} = -grad(P) + \rho_0 \vec{F}$$ Euler (2)

$$\frac{\partial \rho}{\partial t} + \rho_0 div(\vec{v}\,) = \rho_0 q$$ Mass (3)

Vortex potential (div v =0)

Rq: $\vec{v} = -grad(\phi) + rot(\psi\,)$

Velocity potential (rot v =0)

Very often $\vec{v} = -grad(\phi)$

No vortex

Wave equation

$$\begin{cases} \Delta P - \dfrac{1}{c^2}\dfrac{\partial^2 P}{\partial t^2} = \rho_0 \left(div(\vec{F}) - \dfrac{\partial q}{\partial t}\right. \\[2ex] \Delta \vec{v} + rot\ rot\ \vec{v} - \dfrac{1}{c^2}\dfrac{\partial^2 \vec{v}}{\partial t^2} = grad\ q - \dfrac{1}{c^2}\dfrac{\partial \vec{F}}{\partial t} \end{cases}$$

Exercice : with eq 1,2,3 show that we obtain these wave equations

□□□□ Very complicated

if

$$\vec{v} = -grad\ (\phi)$$
$$\vec{F} = -grad\ (U)$$

then

$$\Delta \phi - \frac{1}{c^2}\frac{\partial^2 \phi}{\partial t^2} = -q + \frac{\partial U}{\partial t}$$

$$P = \rho_0 \frac{\partial \phi}{\partial t} - \rho_0 U \qquad \text{Euler}$$

ϕ gives v et P

Without sources

$$\Delta\phi - \frac{1}{c^2}\frac{\partial^2 \phi}{\partial t^2} = 0$$

$$\Delta P - \frac{1}{c^2}\frac{\partial^2 P}{\partial t^2} = 0$$

$$\Delta\vec{v} - \frac{1}{c^2}\frac{\partial^2 \vec{v}}{\partial t^2} = 0$$

$$\rho_0 \frac{d\vec{v}}{dt} = -grad(P)$$

General form

$$\phi(x,t) = F(t \pm \frac{x}{c}) = f((x \pm ct)$$

Exo : demonstrate that the above form is solution

For a plane wave propagating in the x direction

$$v_x = V_M e^{j(\omega t - kx)}$$

Toward x>0

$$j\omega\rho_0 v_x = -\frac{\partial P}{\partial x} = jkP = j\frac{\omega}{c}P$$

$$P = \rho_0 c v_x$$

Energy considerations

Kinetic energy density $E_C = \frac{1}{2}\rho_0 v^2$ [J/m3]

Potential energy $dW = -PdV$ [J]

Remember the state equation

$$P = c^2 \rho$$

Per vol unit $dE_{P=} \frac{dW}{V} = P\frac{d\rho}{\rho_0} = \frac{c^2}{\rho_0}\rho d\rho$

then $E_P = \frac{1}{2}\frac{c^2}{\rho_0}\rho^2 = \frac{1}{2}\frac{P^2}{\rho_0 c^2}$

Energy density (J/m3) :

$$E_I = E_C + E_{P=} \frac{1}{2}\rho_0 v^2 + \frac{1}{2}\frac{P^2}{\rho_0 c^2}$$ In J/m3

Acoustic intensity:

$v = V_m \sin(\omega t - kx)$ $P = P_m \sin(\omega t - kx)$

The acoustic intensity is $\mathrm{I} = Pv$ $\quad$ $in\ W/m^2$

$$\mathrm{I} = P_m V_m\, sin^2(\omega t - kx)$$

$$\langle I \rangle = \frac{P_m V_m}{2}$$

Harmonic regime

$$\tilde{v} = V_m e^{i(\omega t - kx)} \qquad \tilde{P} = P_m e^{i(\omega t - kx)}$$

Complex quantities contain information on the magnitudes and phases of the wave.

Average Intensity

$$\langle I \rangle = \frac{\tilde{P}\tilde{v}^*}{2}$$

Rq 1: acoustic impedance

$$Z = \frac{P}{v} = |Z| e^{j\phi}$$

For a plane wave $Z = \rho_0 c$ Acoustic impedance in kg m^{-2} s^{-1}

Or Rayl (Lord Rayleigh)

Rq 2: $E_I = E_C + E_{P=} \frac{1}{2}\rho_0 v^2 + \frac{1}{2}\frac{P^2}{\rho_0 c^2}$

$$E_I = \frac{1}{2}\rho_0 v^2 + \frac{1}{2}\frac{P^2}{\rho_0 c^2} = \frac{1}{2c}\frac{P^2}{Z} + \frac{1}{2c}\frac{P^2}{Z} = \frac{P^2}{cZ}$$

$$\langle I \rangle = \frac{Pv^*}{2} = \frac{1}{2} Z v^2 = \frac{1}{2}\frac{P^2}{Z} = cE_I$$

RMS pressure $P_{rms} = \frac{P_m}{\sqrt{2}}$ RMS velocity $v_{rms} = \frac{v_m}{\sqrt{2}}$

$$E_I = \rho_0 v_{rms}^2 + \frac{P_{rms}^2}{\rho_0 c^2}$$

P and v are conjugated variables like U et I in electricity

Electricity		Acoustic
$U = RI$		$P = Zv$
$P = UI$	sinus	$I = Pv$
$P = \frac{1}{2} RI^2$		$I = \frac{1}{2} Zv^2$
$P = \frac{1}{2} \frac{U^2}{R}$		$I = \frac{1}{2} \frac{P^2}{Z}$

Order of magnitude

Audible sounds

Air: ρ=1,28 kg/m3 c = 340 m/s

Z = 440 Rayl

Limit of sensitivity of the human ear 10^{-12} W/m^2 or P_r =2 10^{-5} Pa à 1 kHz

$$I_{dB} = 10\log_{10}\frac{I}{I_s} \quad \text{ou} \quad I_{SPL} = 20\log_{10}\frac{P_{eff}}{P_r}$$

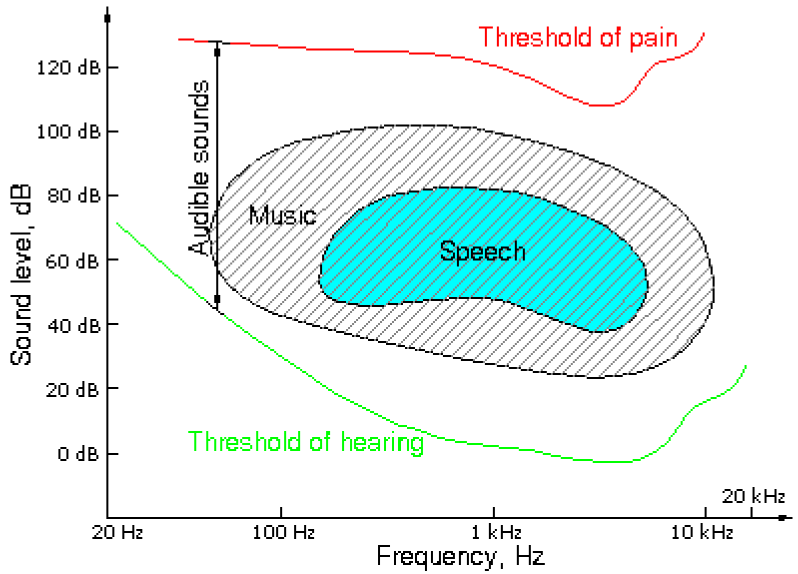
Quite house

air sound 40 à 50 dB

Conversation : 60 dB soit 10^{-6} W/m^2

concert: 80 à 90 dB

aircraft: 120 dB threshold of pain



Exercice : Calculate the mean displacement and velocity
f = 1 kHz I = 60 dB, in air

In W/m^2 $\langle I \rangle = 10^{-6}/10^{-12}$

The compIex particle velocity is $v = V_m e^{i(\omega t - kx)}$,
`In air $Z = \rho_0 c = 440\ Rayl$ and thus the intensity is :

$$\langle I \rangle = \frac{1}{2} Z v^2 = \frac{1}{2} Z V_m^2$$

The particle velelocity is

$$V_m = \sqrt{\frac{2\langle I \rangle}{Z}} = \sqrt{\frac{2 * 10^{-6}}{440}} = 67\ \mu m/s$$

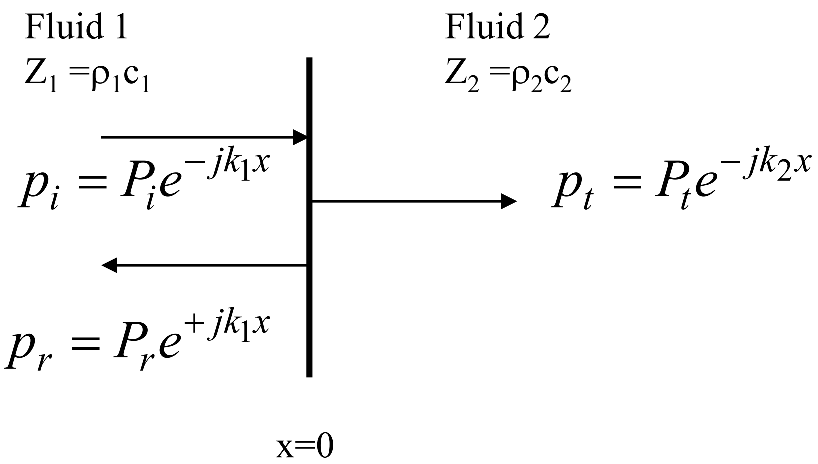
$$U_m = \frac{V_m}{\omega} = \frac{V_m}{2\pi f} = 10\ nm!!!$$

In water Calculate the mean displacement and velocity
f = 5 MHz I = I = I_{max} =100 mW/cm² in water
Density ρ=1000 kg/m3 Celerity c = 1500 m/s

$V_m = 3.6\ cm/s$
$U_m = 1.2\ nm$

Transmission and reflexion (plane waves)

Normal incidence



Reflexion coefficient

$$r = \frac{p_r}{p_i}$$

Transmission Coefficient

$$t = \frac{p_t}{p_i}$$

En x = 0 : continuity equations

$$p_i + p_r = p_t$$

$$v_i + v_r = v_t$$

With $p = \pm Zv$
Depending on the direction

$$\frac{p_i}{Z_1} - \frac{p_r}{Z_1} = \frac{p_t}{Z_2}$$

Amplitude transmission coeffcient

$$r = \frac{Z_2 - Z_1}{Z_2 + Z_1} \qquad t = \frac{2Z_2}{Z_2 + Z_1}$$

Energy transmission coefficient

$$R = \frac{I_r}{I_i} = \frac{p_r^2 Z_1}{Z_1 p_i^2} = r^2 \qquad R = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2$$

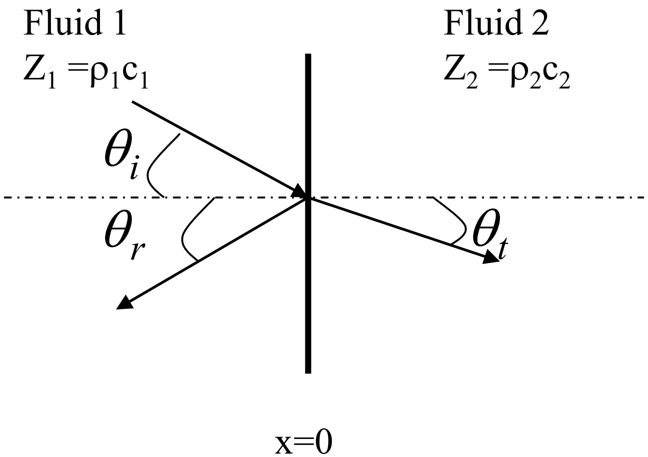
$$T = \frac{I_t}{I_i} = \frac{p_t^2 Z_1}{Z_2 p_i^2} = \frac{Z_1}{Z_2} t^2 \qquad T = \frac{4Z_1 Z_2}{(Z_2 + Z_1)^2}$$

with: $R+T=1$ energy is conservative

Exercice: Determine the transmission coefficient between air and water

In air $Z = 440\ Rayl$ in water $Z = 1.5\ 10^6\ Rayl$ thus
R =0.9988 and T =0.0012
In dB, the attenuation due tu transmission is close to 30 dB

Oblique incidence



Like in optics

$$\theta_i = \theta_r$$

and $$\frac{\sin\theta_i}{c_1} = \frac{\sin\theta_r}{c_2}$$

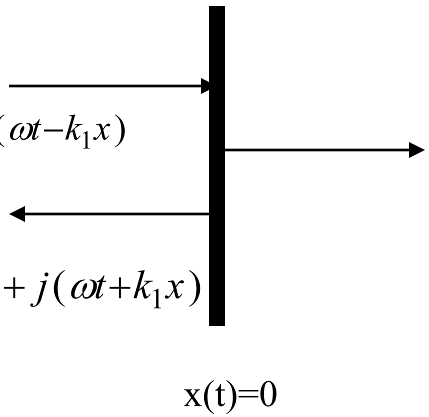
if $$\sin\theta_i = \frac{c_1}{c_2}$$ Total reflexion

$$r = \frac{Z_2\cos\theta_i - Z_1\cos\theta_t}{Z_2\cos\theta_i + Z_1\cos\theta_t} \qquad t = \frac{2Z_2\cos\theta_i}{Z_2\cos\theta_i + Z_1\cos\theta_t}$$

Exemple : propagation through a rigid wall surface density μ in kg/m²

Normal incidence

$Z_1 = \rho_1 c_1$ $\qquad$ $Z_1 = \rho_1 c_1$



$$p_i = P_i e^{j(\omega t - k_1 x)}$$

$$p_t = P_t e^{j(\omega t - k_1 x)}$$

$$p_r = P_r e^{+j(\omega t + k_1 x)}$$

$$v_i + v_r = v_t \qquad \frac{p_i}{Z_1} - \frac{p_r}{Z_1} = \frac{p_t}{Z_2} = v(t)$$

thus $\quad p_r = p_i - \dfrac{Z_1 p_t}{Z_2}$

Dynamic equation

$$p_i + p_r - p_t = \mu \frac{dv(t)}{dt}$$

If $Z_1 = Z_2$

For a sinusoidal wave

$$p_i + p_i - p_t - p_t = \mu \frac{dv(t)}{dt} = j\omega\mu \frac{p_t}{Z_1} \qquad p_i - p_t = j\frac{\omega\mu}{2}\frac{p_t}{Z_1}$$

$$t\left(1 + j\frac{\omega\mu}{2}\frac{1}{Z_1}\right) = 1$$

Low pass filter

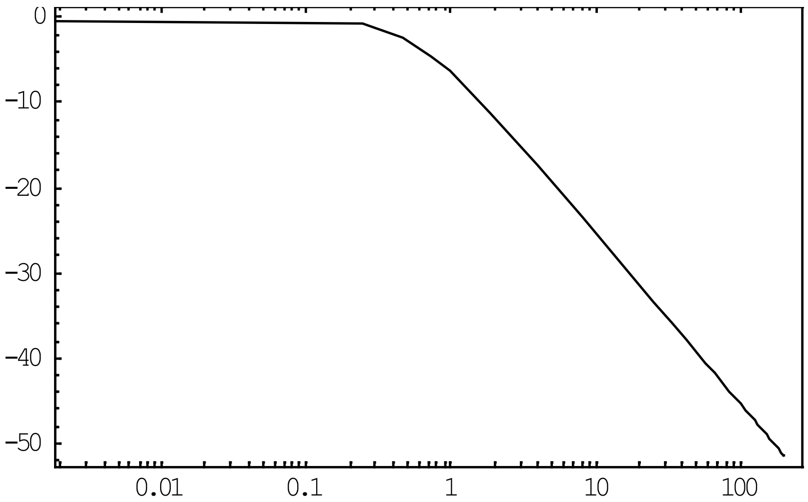
$$t = \frac{p_t}{p_r} = \frac{1}{1 + j\dfrac{\omega\mu}{2\rho_1 c_1}}$$

Et $$T = \left|\frac{p_t}{p_r}\right|^2 = \frac{1}{1 + \left(\dfrac{\omega\mu}{2\rho_1 c_1}\right)^2}$$

Numerical application

Concrete wall: *e =10 cm,* ρ*=2600 kg/m³ =>* μ *= 260 kg/m²*

T =46 dB à 100 Hz



Attenuation due to viscosity. η, μ

Dynamic equation

$$\rho_0 \frac{d\vec{v}}{dt} = -grad(P) + (\eta + \frac{4}{3}\mu)\Delta\vec{v}$$ i.e $$\frac{d^2\vec{u}}{dt^2} = c^2\Delta\vec{u} + \frac{1}{\rho_0}(\eta + \frac{4\mu}{3})\Delta\frac{d\vec{u}}{dt}$$

Harmonic regime $u_x = U_M e^{j(\omega t - kx)}$

$$\frac{d^2\vec{u}}{dt^2} = (c^2 + j\omega\frac{1}{\rho_0}(\eta + \frac{4\mu}{3}))\Delta\vec{u}$$

Complex celerity

$$c^{2^*} = c^2(1 + j\omega\frac{1}{\rho_0 c^2}(\eta + \frac{4\mu}{3}))$$ First order dev. : $c = c(1 + j\omega\frac{1}{2\rho_0 c^2}(\eta + \frac{4\mu}{3}))$

Complex wave number $$k^* = \frac{\omega}{c^*} = \frac{\omega}{c}(1 - j\omega\frac{1}{2\rho_0 c^2}(\eta + \frac{4\mu}{3}))$$

Expression of the particule displacement

$$u_x = U_M e^{j(\omega t - k^* x)}$$

Soit

$$u_x = U_M e^{j(\omega t - \frac{\omega}{c} x)} e^{-\alpha x}$$

Propagation — Attenuation

Attenuation coefficient

$$\alpha = \frac{\omega^2}{2\rho_0 c^3}(\eta + \frac{4\mu}{3})x$$

Neper/m

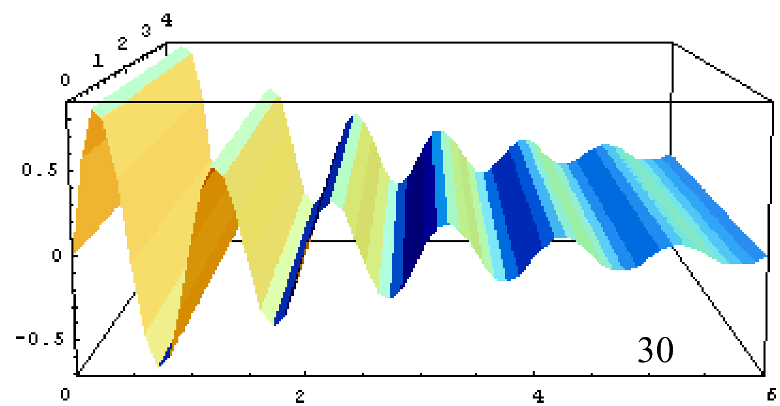
In dB

$$A(dB) = 20\log_{10}(e^{-\alpha x}) = 8.686\alpha\, x$$

$$A(dB) = 8{,}686\frac{\omega^2}{2\rho_0 c^3}(\eta + \frac{4\mu}{3})x$$

Attenuation proportionnal to the square frequency

Other causes : thermal conductivity
Molecular relaxation



Attenuation in air in dB/m at 1 kHz, 1 MHz,
μ = 1.910-5, η=0.6μ

What is the viscous interaction length?

$$\alpha = \frac{\omega^2}{2\rho_0 c^3}(\eta + \frac{4\mu}{3})x$$

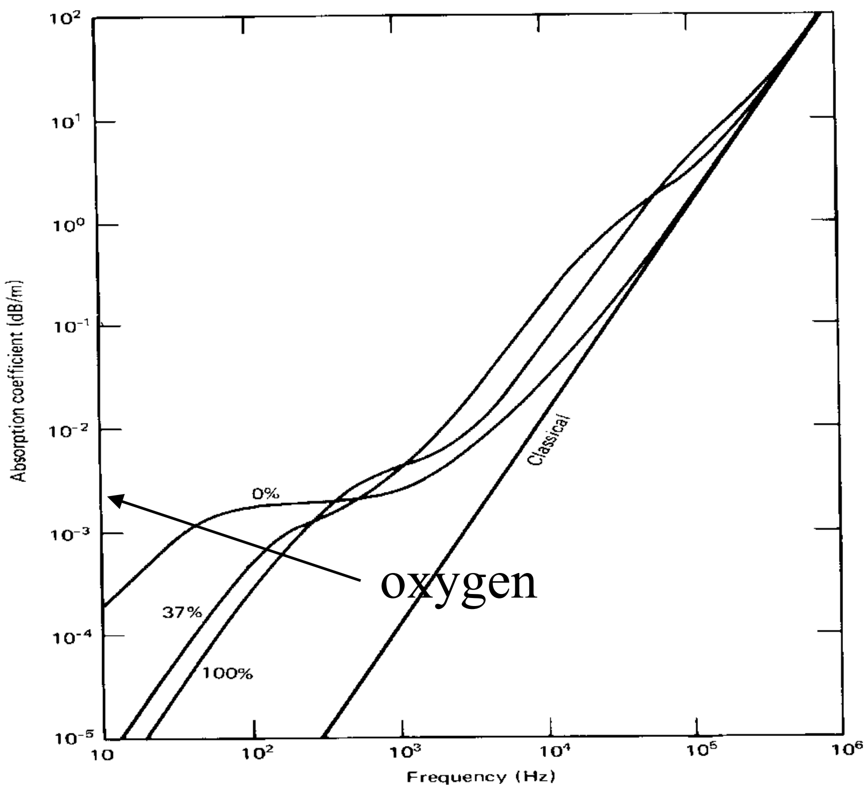


Fig. 7.3. Absorption of sound in air at 20°C as a function of frequency. (After Bass, et al.)

@ 1 kHz
$\delta = 150\ km$!!
@ 1 MHz
$\delta = 0.15\ m$

Attenuation in liquids

$\eta << \mu$

$$\alpha \approx \frac{\omega^2}{\rho_0 c^3}\frac{2\mu}{3}x$$ In Neper

α_{water}=0.22 dB/m

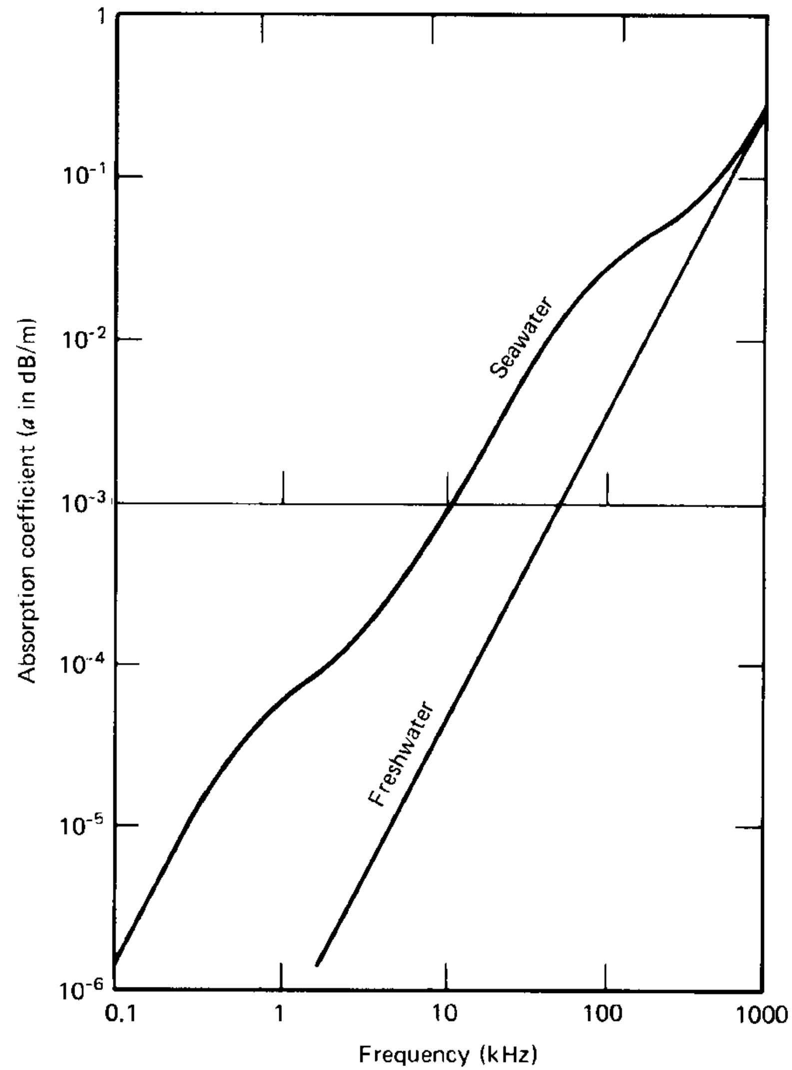


Fig. 7.5. Sound absorption in freshwater and in seawater (35 ppt *salinity*) *at* 5°C *and* 1 atm. (*According to Fisher and Simmons.*)

Conclusion

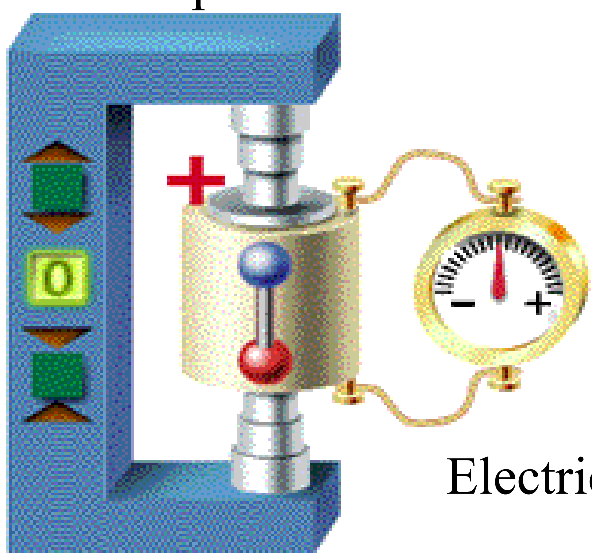
- Some concepts have been defined such as wave characteristics, acoustic impedance, transmission reflexion coefficients, attenuation factor…
- These concepts are essentials understand the interaction of a wave with mater, it is essential to know the essential characteristics of the wave celerity attenuation.
- We will use these concept to understand the electroacoustic behavior of a transducer and the wave interaction with materials

Few words on Piezoelectricity

Définition
Material properties
Ferroelectric materials

The piezoelectricity is the property of several materials that are able to generate an electric charge when mechanically deformed. Conversely, when an external electric field is applied to piezoelectric materials they mechanically deform.

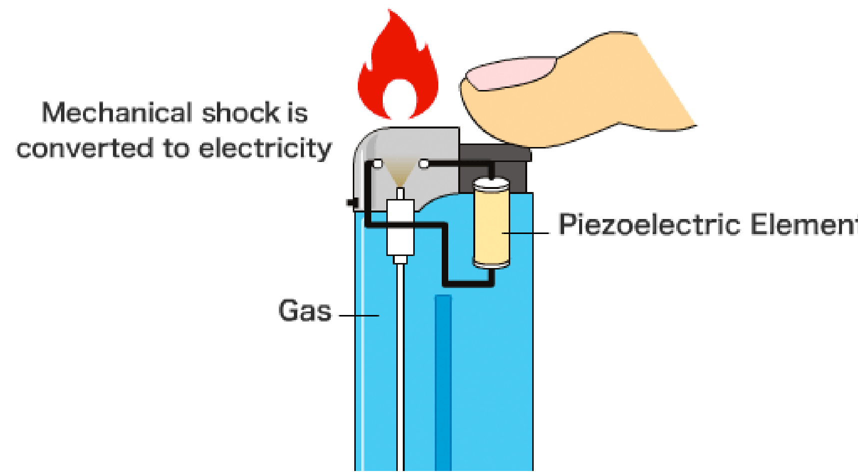
Mecanic pressure



Electric signal

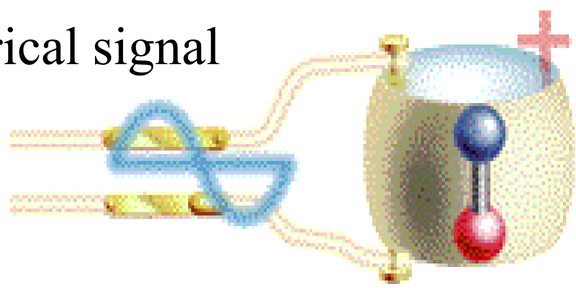
Direct effet

Lighter sensors



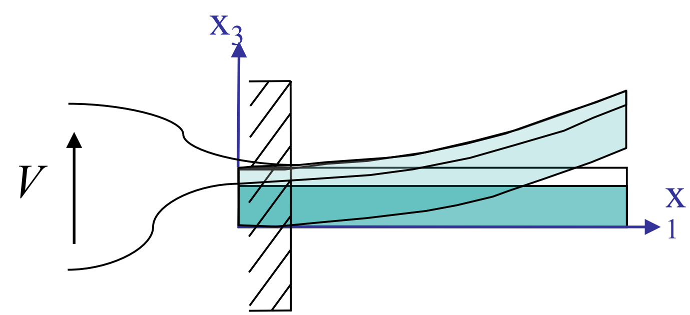
Mechanical to electrical energy conversion and conversely

Electrical signal



Mechanical displacement

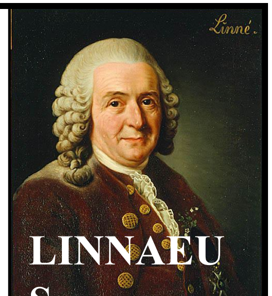
actuators

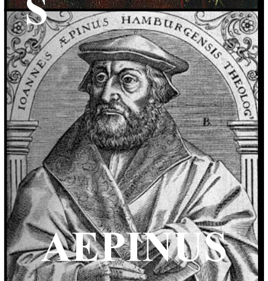


Inverse effet

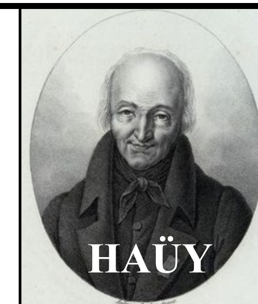
Discovery of the piezoelectric effect

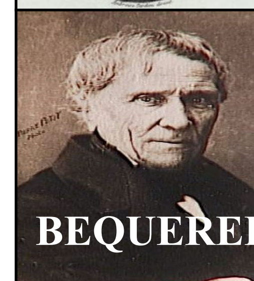
Pyroelectricity – studied c. 1750





Piezoelectricity – early experimental work c. 1820

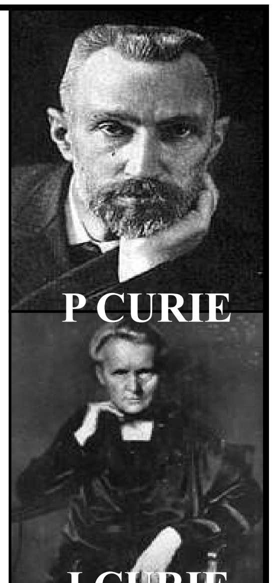


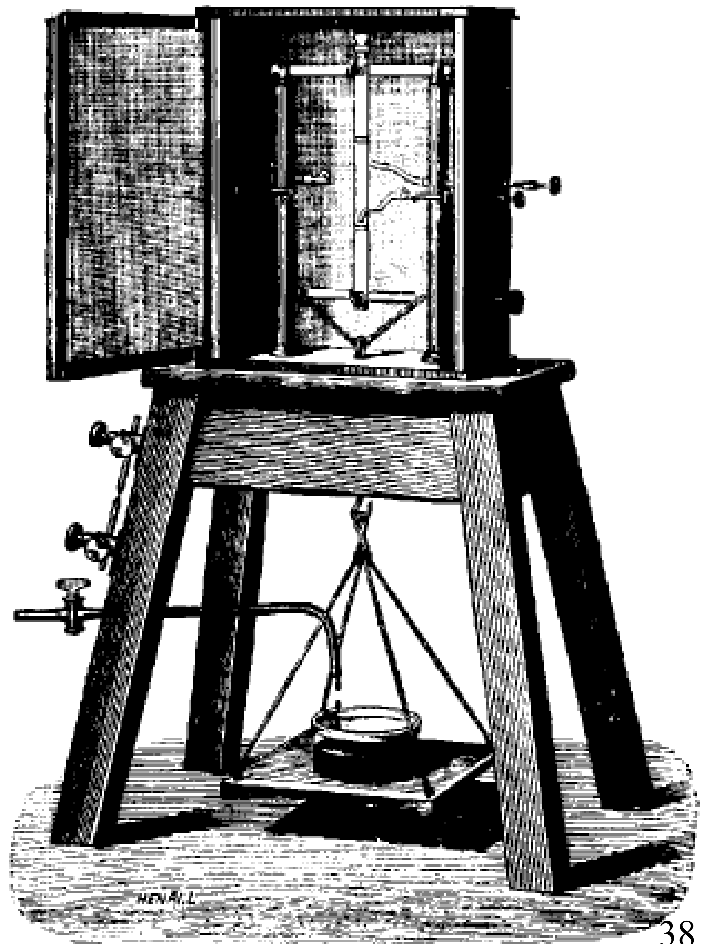


Discovery of the piezoelectric effect

Curie brothers discover that several material are producing charges under mechanical deformation

Experimental evidence in1880





Discovery of the piezoelectric effect

Pyroelectricity – studied c. 1750

Liné and Apineus

Piezoelectricity –c. 1820

Hauy and Becquerel

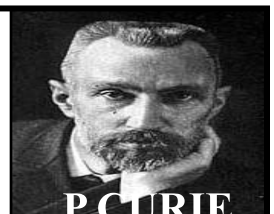
Piezoelectricity – confirmed 1880

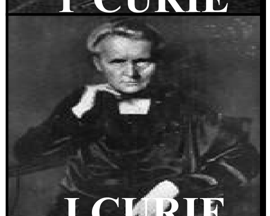
Curie Brothers

Converse piezoelectricity – predicted 1881

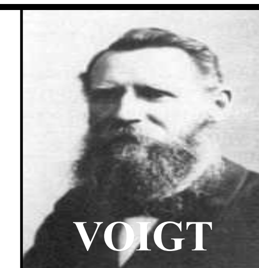
Lipman

Converse piezoelectricity – confirmed 1881

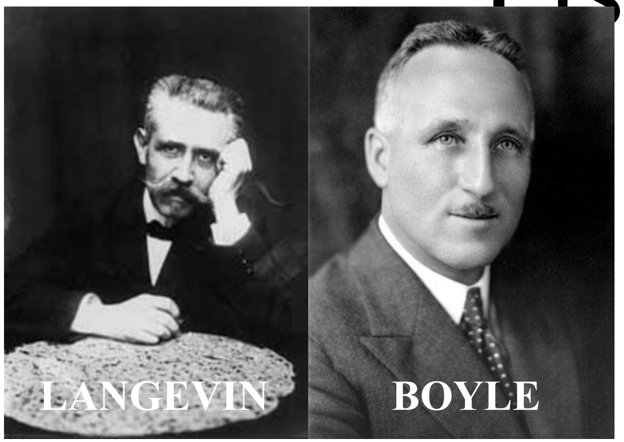




Piezoelectric theory – refined 1910

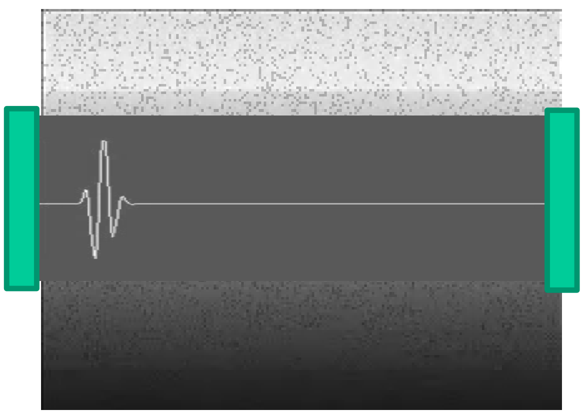


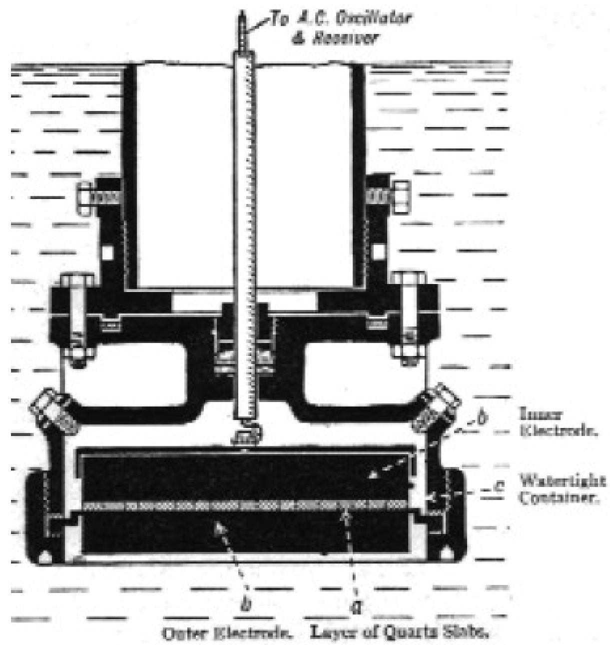
Fisrt World War



1916: ultrasonic transmission using Quartz crystal

Work commissioned by the Anti-Submarine Division, in a joint research effort by the French, British and American lead to the development of early sonar (ASDIC)





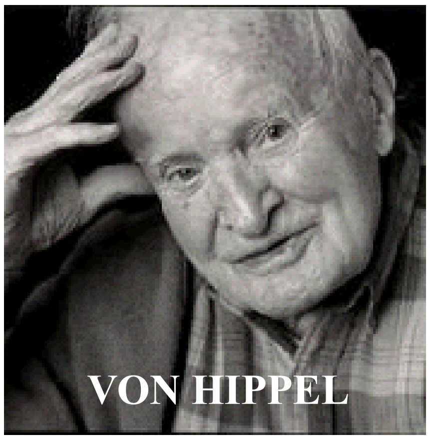
Quartz Transducer sandwich type h (A. B. Wood, A Textbook of Sound (1932))

6164__NoiseCollector__jillys_sonar.wav

6165__NoiseCollector__jillys_sonar2.wav

World War II & beyond

The origin of the high dielectric constant in barium titanate was discovered to be a result of its ferroelectric properties



High dielectric constant ceramics

A. von Hippel, R. G. Breckenridge, F. G. Chesley, and Laszlo Tisza

LABORATORY FOR INSULATION RESEARCH, MASSACHUSETTS INSTITUTE OF TECHNOLOGY, CAMBRIDGE, MASS.

Results of an investigation are presented in this paper on titanium dioxide and the alkaline earth titanates, including some mixtures and solid solutions of the barium and strontium compounds. Dielectric measurements over a wide range of frequencies, temperatures, and voltages, and thermal expansion and x-ray studies have yielded a rather complete picture of the properties and usefulness of these titania ceramics. Barium titanate and the barium-strontium titanate solid solutions prove to be a new class of ferroelectric materials. Their peculiar dielectric behavior was first noted by the Titanium Alloy Manufacturing Company, and this behavior proves to be connected with a lattice transition from pseudocubic to cubic. Additional maxima have been found in the dielectric characteristics which correspond to transitions of the second order. These maxima are being studied further.

XCVI. *Theory of Barium Titanate.*—Part I.

By A. F. Devonshire,
H. H. Wills Physical Laboratory, University of Bristol*.

[Received July 26, 1949.]

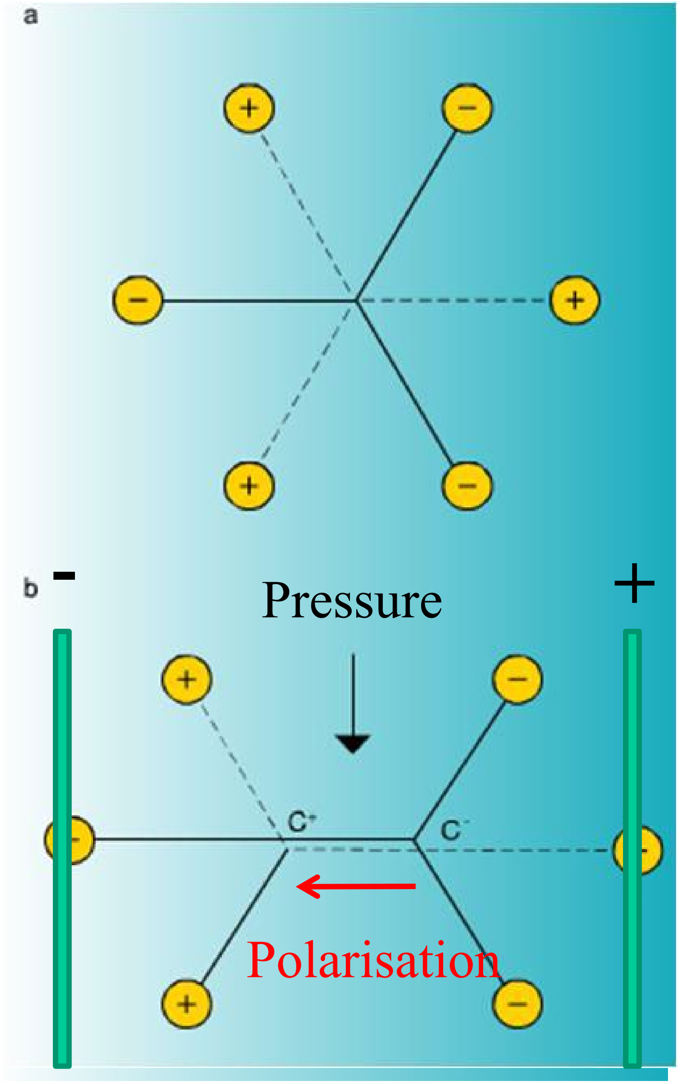
Summary.

The theory of the dielectric and crystallographic properties of barium titanate is considered. By expanding the free energy as a function of polarization and strain and making reasonable assumptions about the coefficients, it is found possible to account for the various crystal transitions. Calculations are made of the dielectric constants, crystal stains, internal energy, and self polarization as functions of temperature. Finally relations are obtained between the coefficients in the free energy and the ionic force constants. These are used to estimate some of the coefficients which are not completely determined by experimental data.

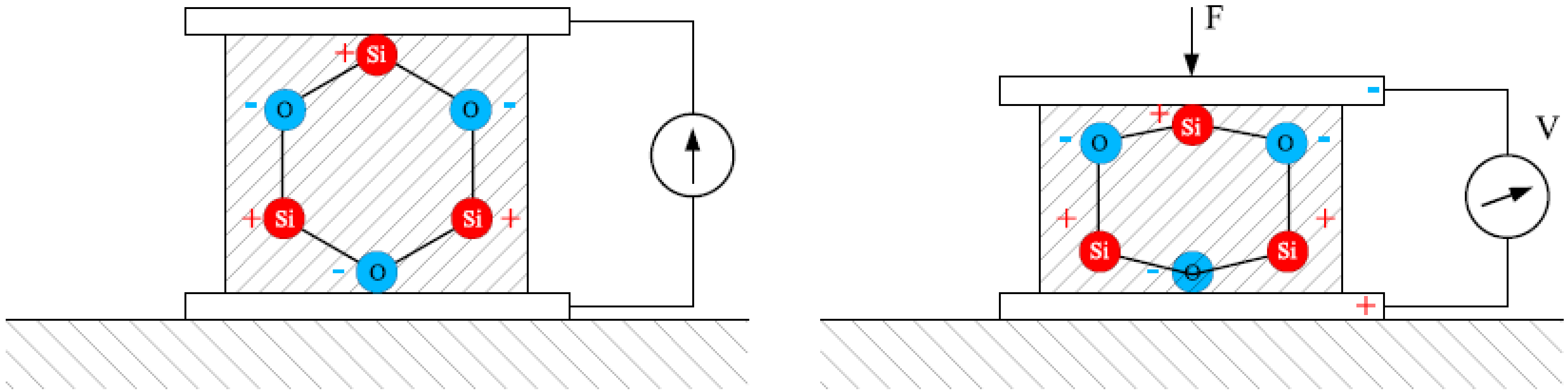
A complete theory predicting the structural phase transitions in $BaTiO_3$ was proposed by Devonshire

Why in several materials

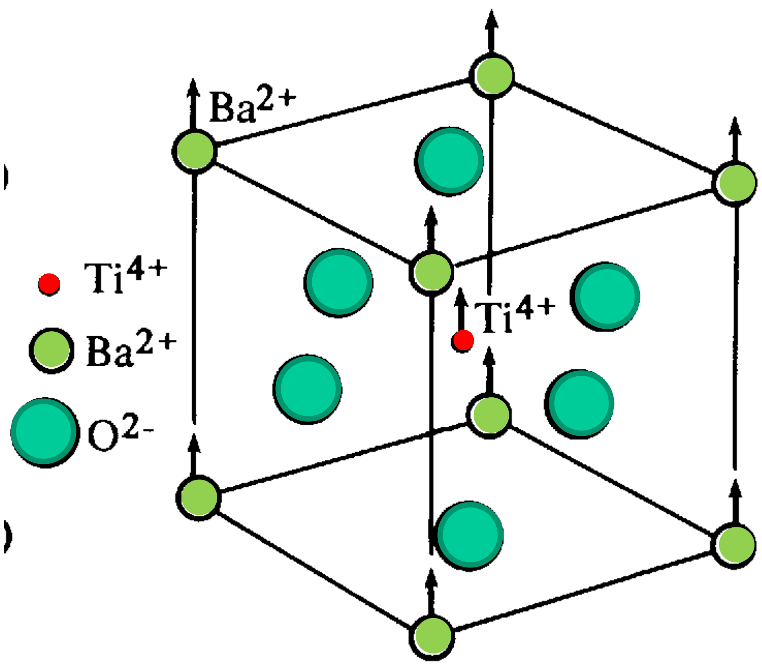
Piezoelectricity appears in non centro symetrical crystals

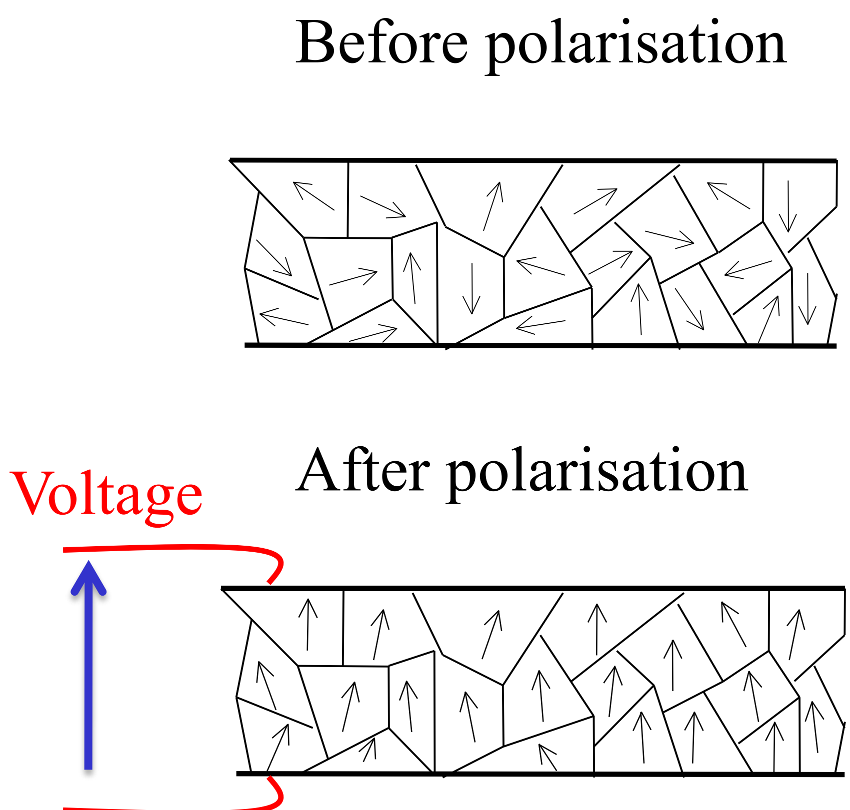


Example: Quartz crystal charges appear on top and bottom faces



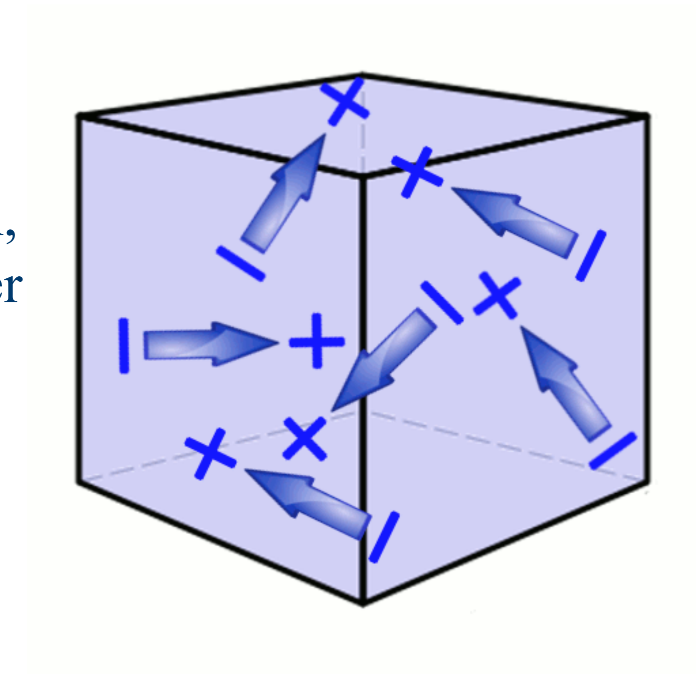
The ferroelectricity and the Piezoelectricity barium titanate ceramics

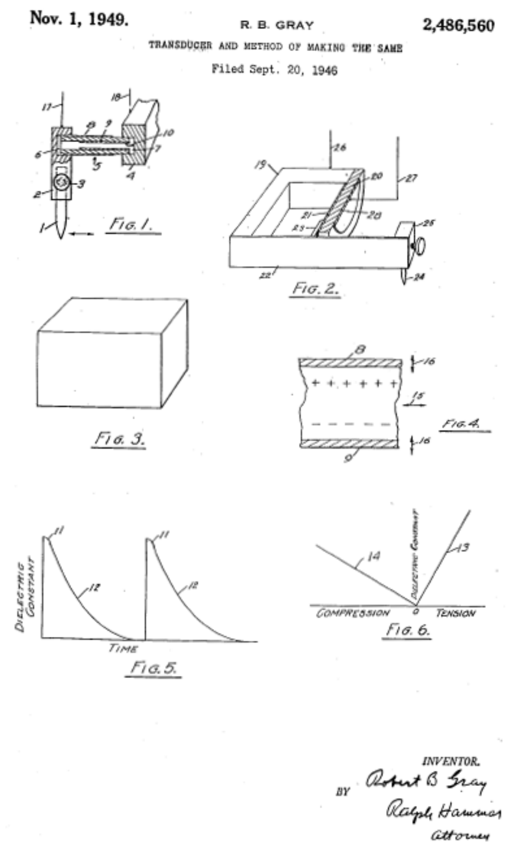


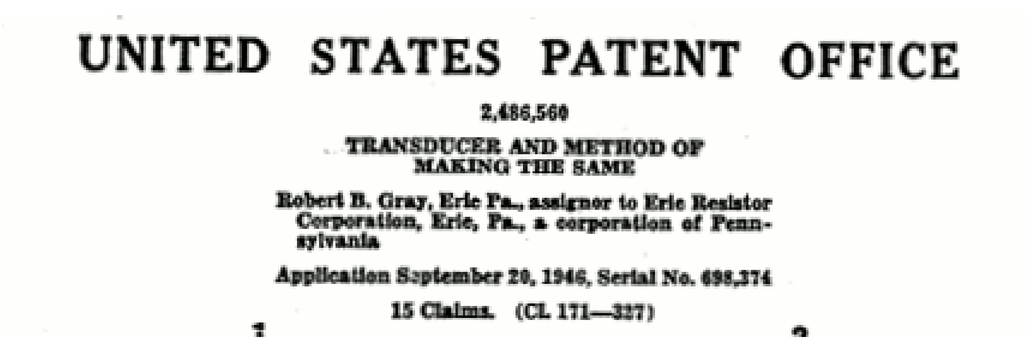


The development of ceramics

In 1949 a US patent was filed by Erie Resistor Corporation, for a piezo transducer that used the first poled ceramic samples.







UNITED STATES PATENT OFFICE

2,486,560

TRANSDUCER AND METHOD OF MAKING THE SAME

Robert B. Gray, Erie Pa., assignor to Erie Resistor Corporation, Erie, Pa., a corporation of Pennsylvania

Application September 20, 1946, Serial No. 698,274

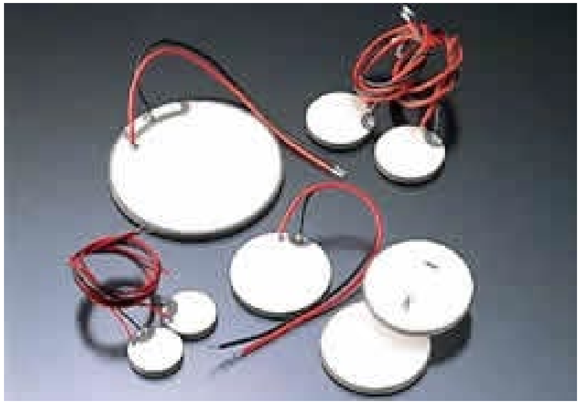
15 Claims. (Cl. 171—327)

PZT and PLZT ceramics

$Pb[Zr_xTi_{1-x}]O_3$ $(0<x<1)$ & $Pb_{1-x}La_x(Zr_yTi_{1-y})_{1-x/4}O_3$

- Higher electromechanical coupling
- Higher TC values, resulting in higher operational and processing temperatures
- Easily poled for applications, versatility
- Possess a wide range of dielectric constants across the phase diagram

Hans Jaffe (far right)

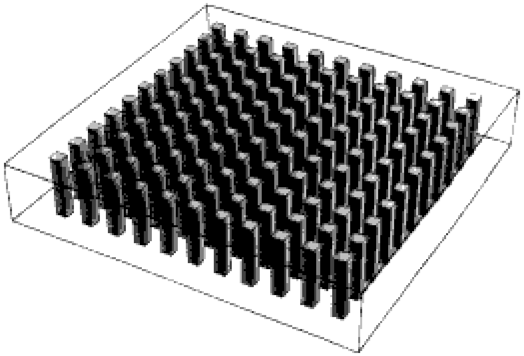


PZT ceramics
(www.fujicera.co.jp)

New technological processes
Enhancement of the performances

1978 : composites materials

R.E. Newnham, D.P. Skinner, L.E. Cross, **Connectivity and piezoelectric-pyroelectric composites**, *Materials Research Bulletin*, *Volume 13, Issue 5*, *May 1978*, *Pages 525-536*

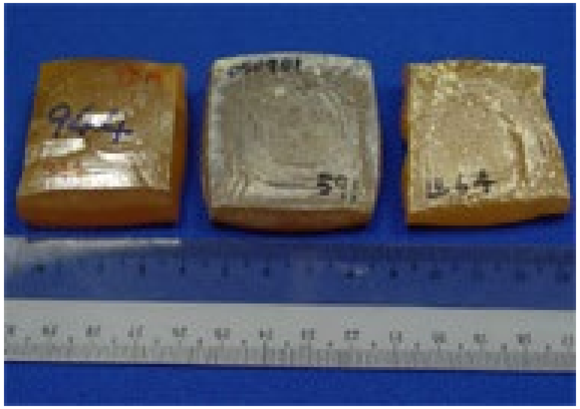


http://www.ndt.net/article/v06n08/fleury/fig1.gif

90 Piezoelectric single crystals with giant properties

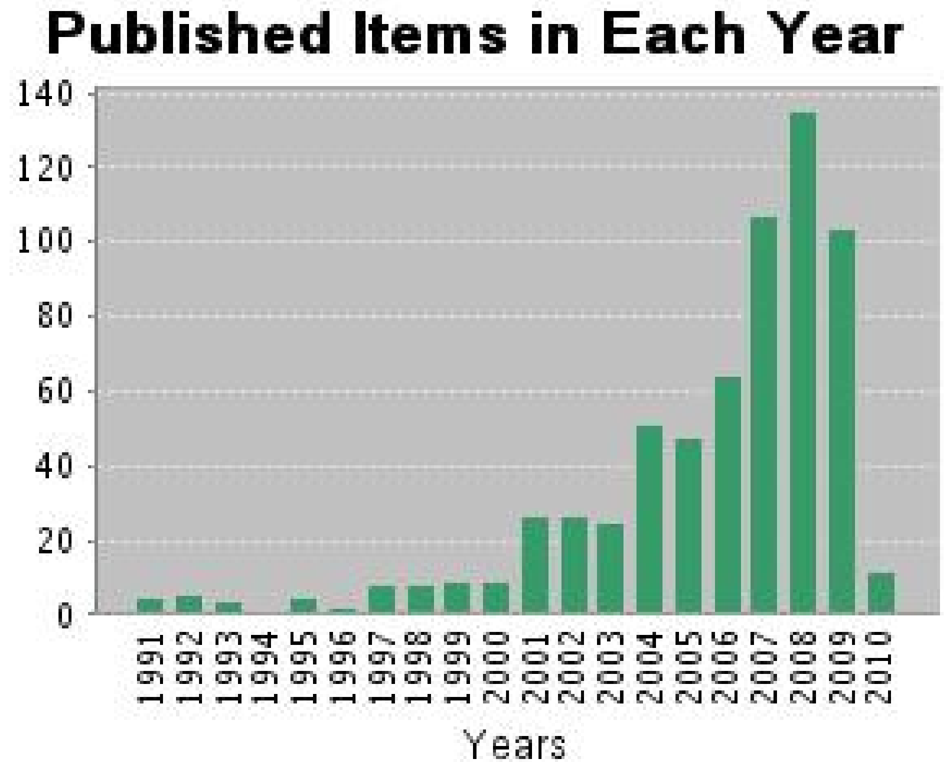
Jun Kuwata, Kenji Uchino, and Shoichiro Nomura, **Phase Transitions in the Pb(ZnlnNbm)O,-PbTiO, System**, *Ferroelecrrics, vol. 37, pp. 579-582, 1981*

T. R. Shout, Z.P. Chang, N. Kim and *S. Markgraf ,* **Dielectric Behavior of single Crystals Near the (1-x)Pb(Mg1/3Nb2/3)03 (x)PbTi03 Morphotropic Phase Boundary**, *Ferroelectr. Let., vol. 12, pp. 63-69, 1990.*



http://www.microfine-piezo.com/

2000 : lead free ceramics



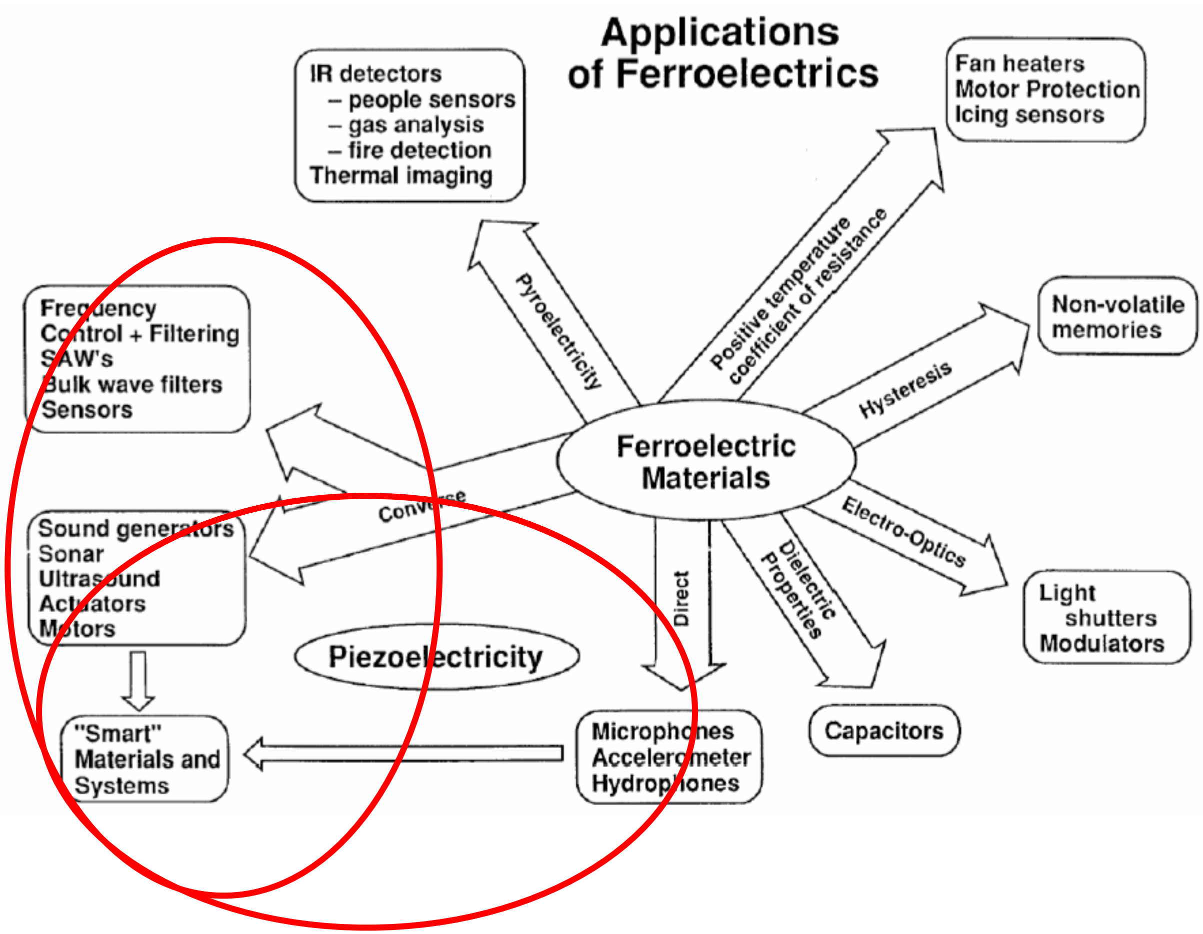
DIRECTIVE 2002/95/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL

of 27 January 2003

on the restriction of the use of certain hazardous substances in electrical and electronic equipment

Accelerometers.

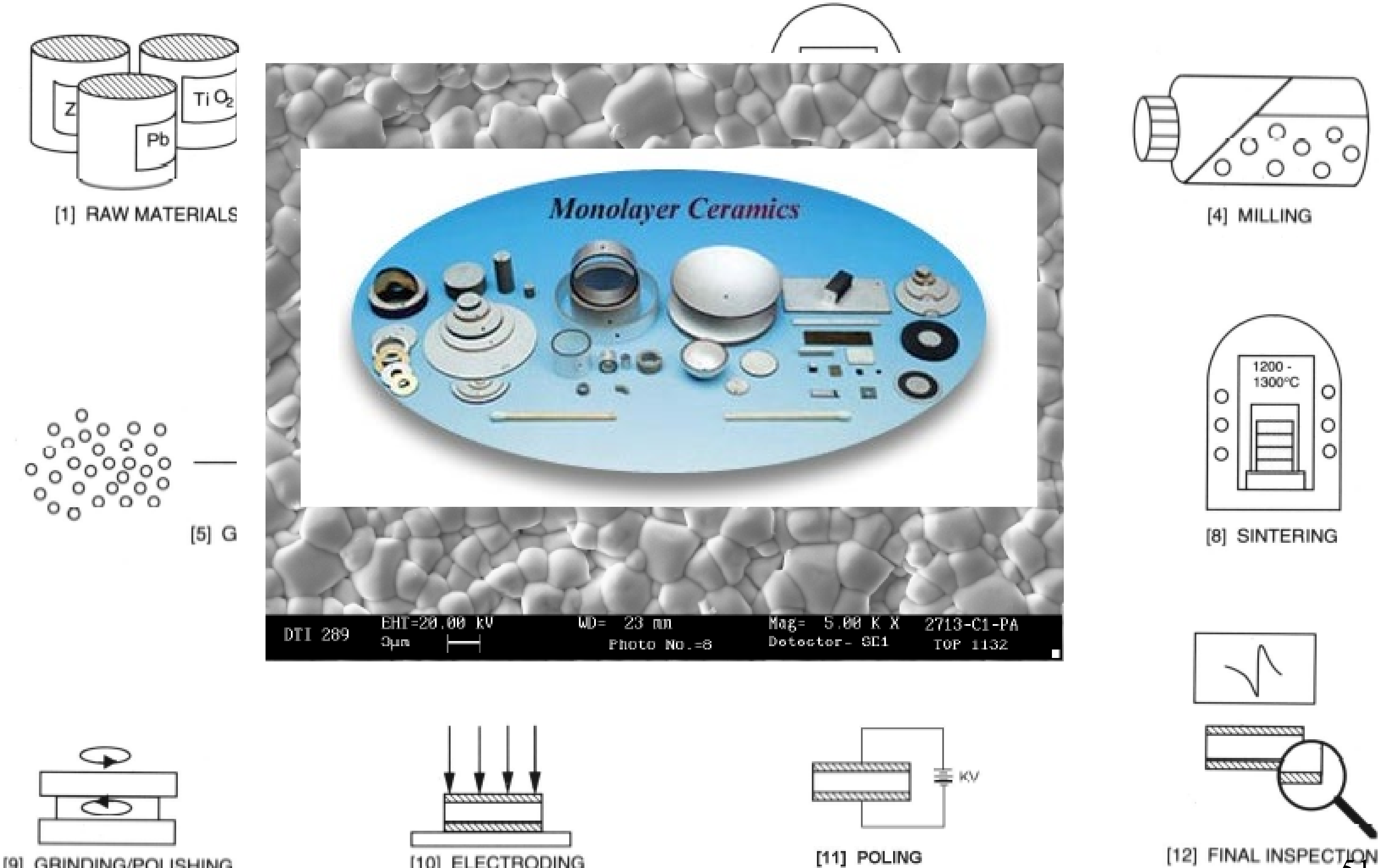
- Flow meters: Blood, industrial processes, waste
water.
- Medical: Imaging, HIFU, IVUS, surgical knives,
and cleaning of blood veins.
- Underwater acoustics: echosounders, sonar
systems, fish-finders, seabed mapping.
- Industrial sensors based on ultrasound: Level
control, detection, and identification.
- Hydrophones: Seismic, biologic, military,
underwater communication.
- Inkjet printheads.
- Dental work: Removal of plaque.
- Alarm systems: Movement detectors, broken
window sensors.
- NDT: Transducers for Non Destructive Testing.
- Musical instrument pickups.
- Acoustic emission transducers.
- Actuators.
- Micro positioning devices: Optics, scanning
tunneling microscopes.
- Surface Acoustic Waves: Personal Computer touch
screens, filters.



Material and properties

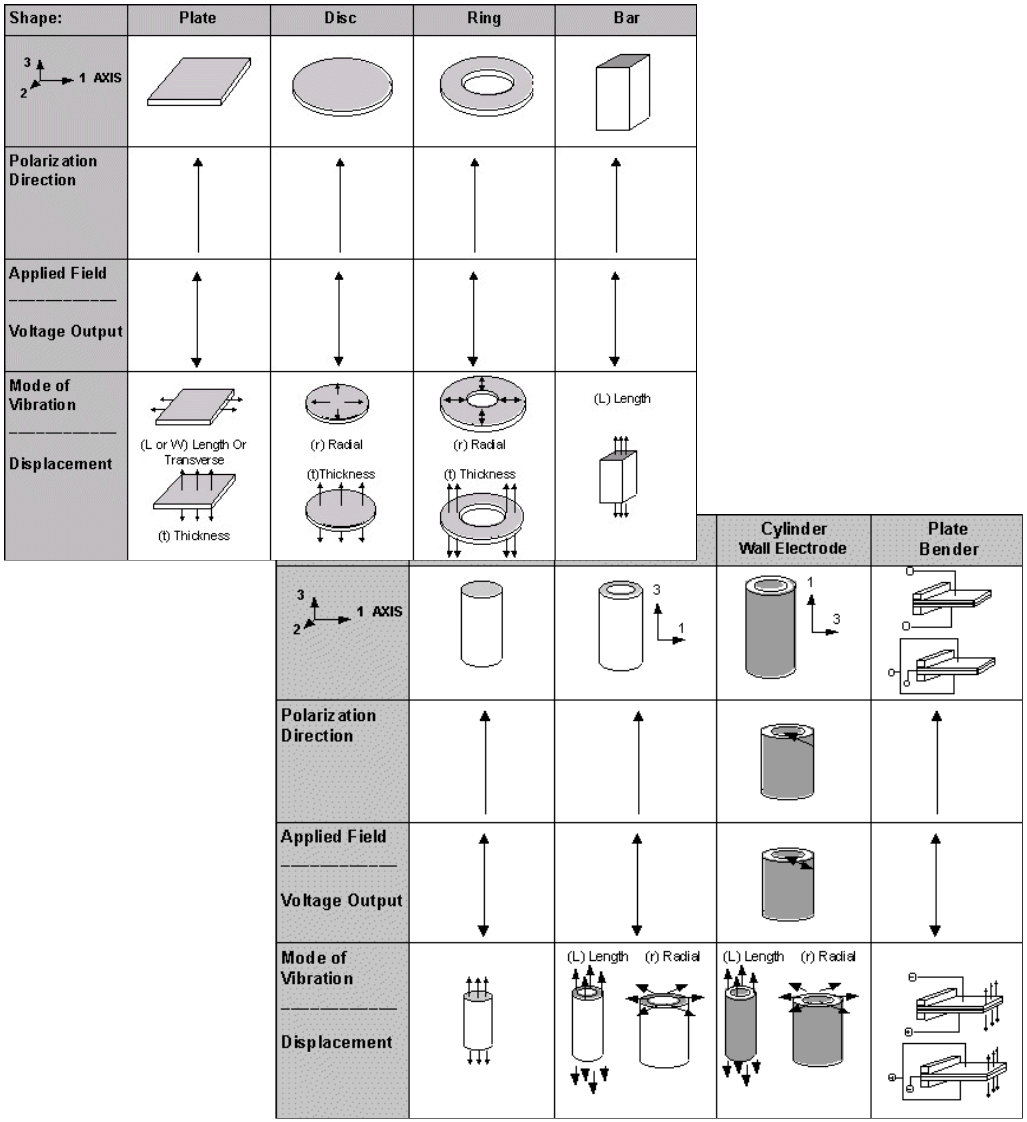
Fabrication process of ceramics

Powder



http://www.ferroperm-piezo.com/

Piezo ceramics



Mains characteristics

- •High stress
- •Linear response
- •Small deformations

Piezo oefficient= 100 pC/N
thickness= 1 mm
Volatge = 10 V

displacement
Δl=1 nm !

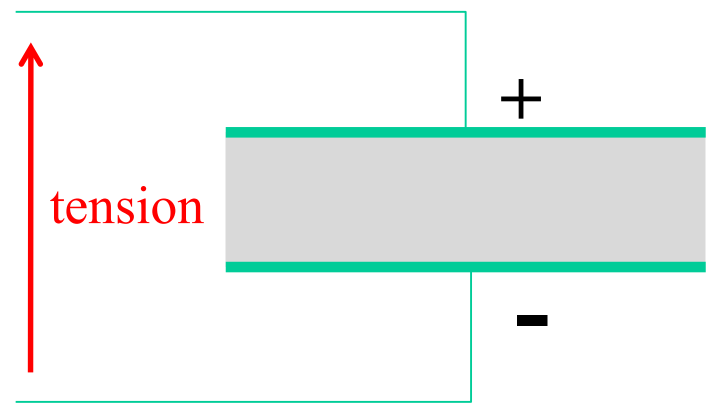
Some properties

Electrical

Piezoelectric material are insulators : caracterised by their ability to accumulate charges

In a conducting metal electrons are free

ε dielectric constant



In a insultator

Electrons are located on electrodes

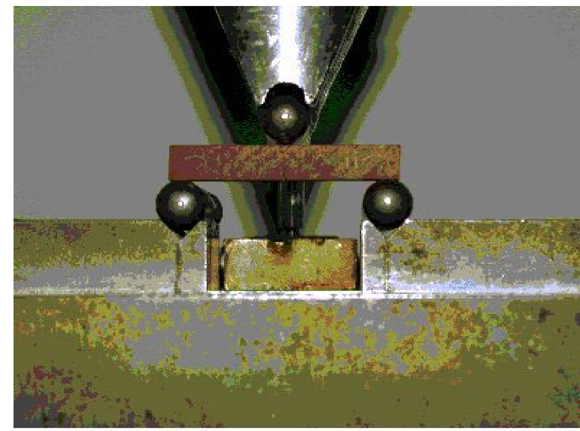
In V/C

Mechanical

Elasticity or stifness

c coefficient

http://www.insep.fr/FR/Sports/Gymnastique/PublishingImages/gymnastique.jpg



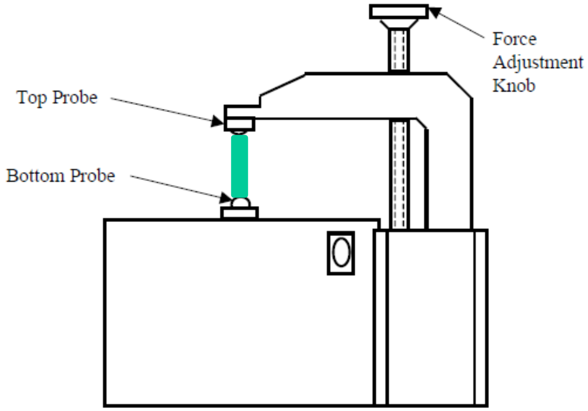
http://www.unilim.fr/theses/2003/sciences/2003limo0004/images/figurevi1.jpg

In Newton per m^2

Electromechanical

Ability to accumulate charges for a given force

http://www.piezotest.com/d33piezometer.htm



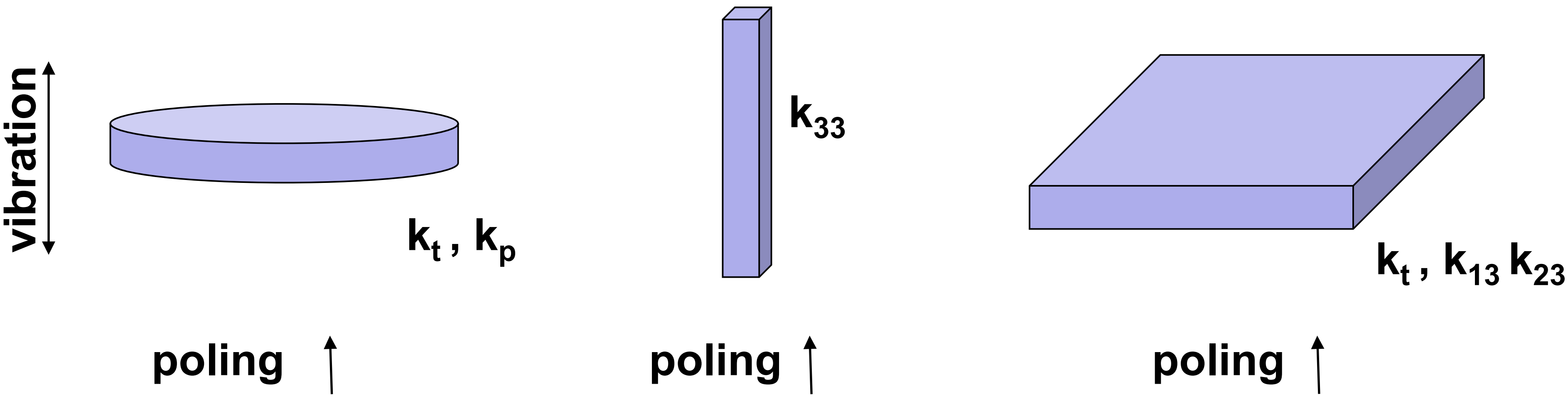
http://www.kcftech.com/products/documents/PM3001.manual.pdf

d coefficient

In Coulomb per Newton or m/Volt

Electromechanical coupling coefficient

The electromechanical coupling factor, *k*, of piezoelectric materials, determines the conversion efficiency of mechanical to electrical energy or electrical to mechanical energy.



The coupling factor, *k*, is associated with a vibration mode and thus do not have a unique expression, k is always bellow 1

Properties

Material	piezo. Coef. d_{33} (10^{-12} m/V)	Relative Permittyvity	Stiffness coef. (10^9N/m²)	Density kg/m3	Thicness coupling coef. (%)
Quartz [1]	2,3	4,5	80	2650	10
Barium Titanante (T57) [2]	105	700	112	5300	40
Lead Titanate (PZ34) [3]	50	210	140	7550	40
Lead Titanate Ziconate (PZ27) [3]	425	1800	113	7700	60
Piezo Polymers	26 [4]	5 [5]	10 [5]	2500 [5]	25 [5]

[1] Morgan Matroc

[2] Quartz et Silice

[3] Ferroperm

[4] Sasaki **ISSN** 0386-2186

[5] Feuillard, thèse de doctorat

Conclusions

•Piezoelectric materials are used as sensor,actuators or transducers in many applications .

•Covered field : **microsystem**, **microelectronics medicine nuclear or aeronautics.**

•**Very often hidden but essential in many applications**

- Piezo materials are known …
- We focused mainly in transducer but they are used in many application
- Now it is time to see how we can use them to make transducers and to produce images…

- To be continued…

Thank you !