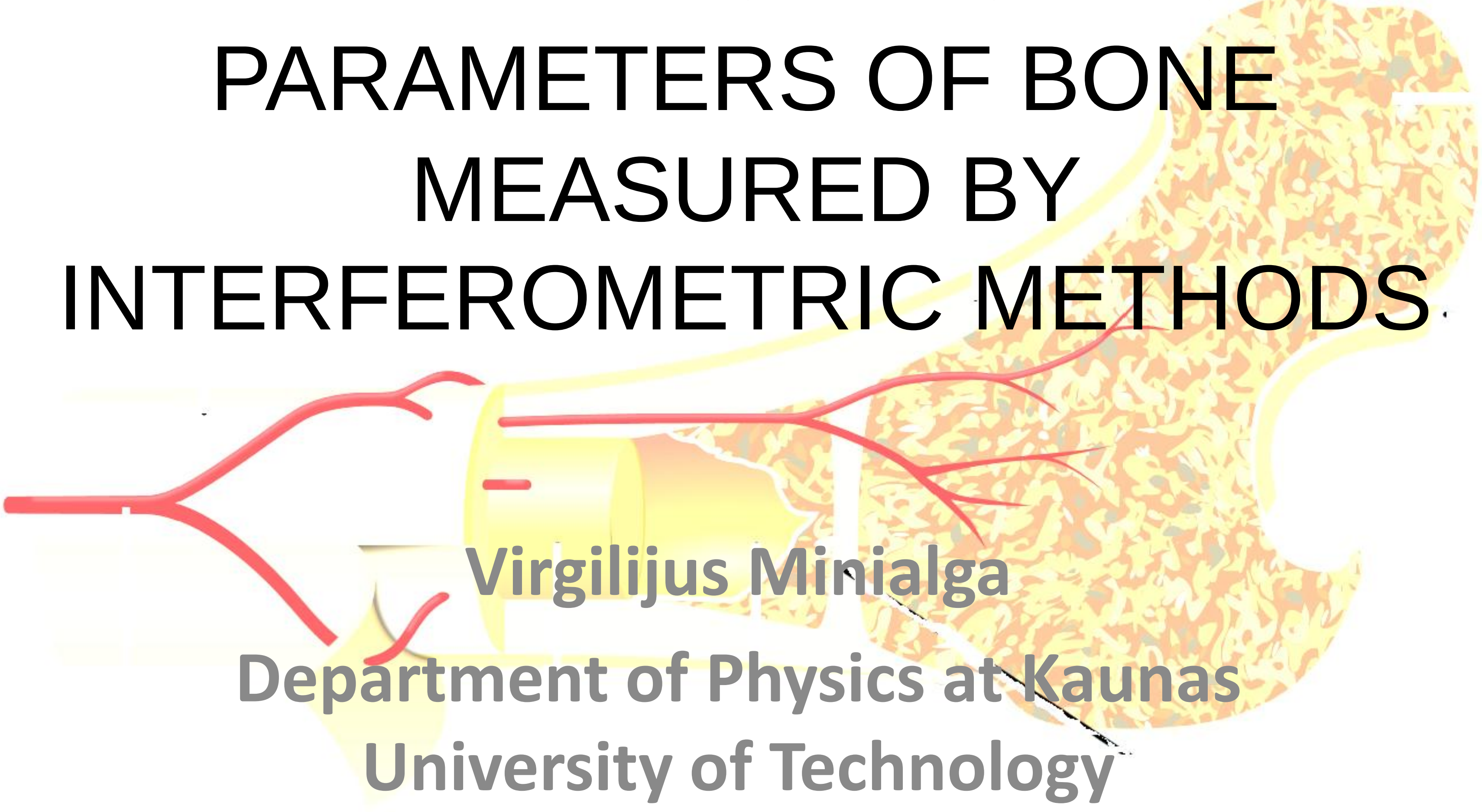
MAIN PIEZOELECTRIC PARAMETERS OF BONE MEASURED BY INTERFEROMETRIC METHODS



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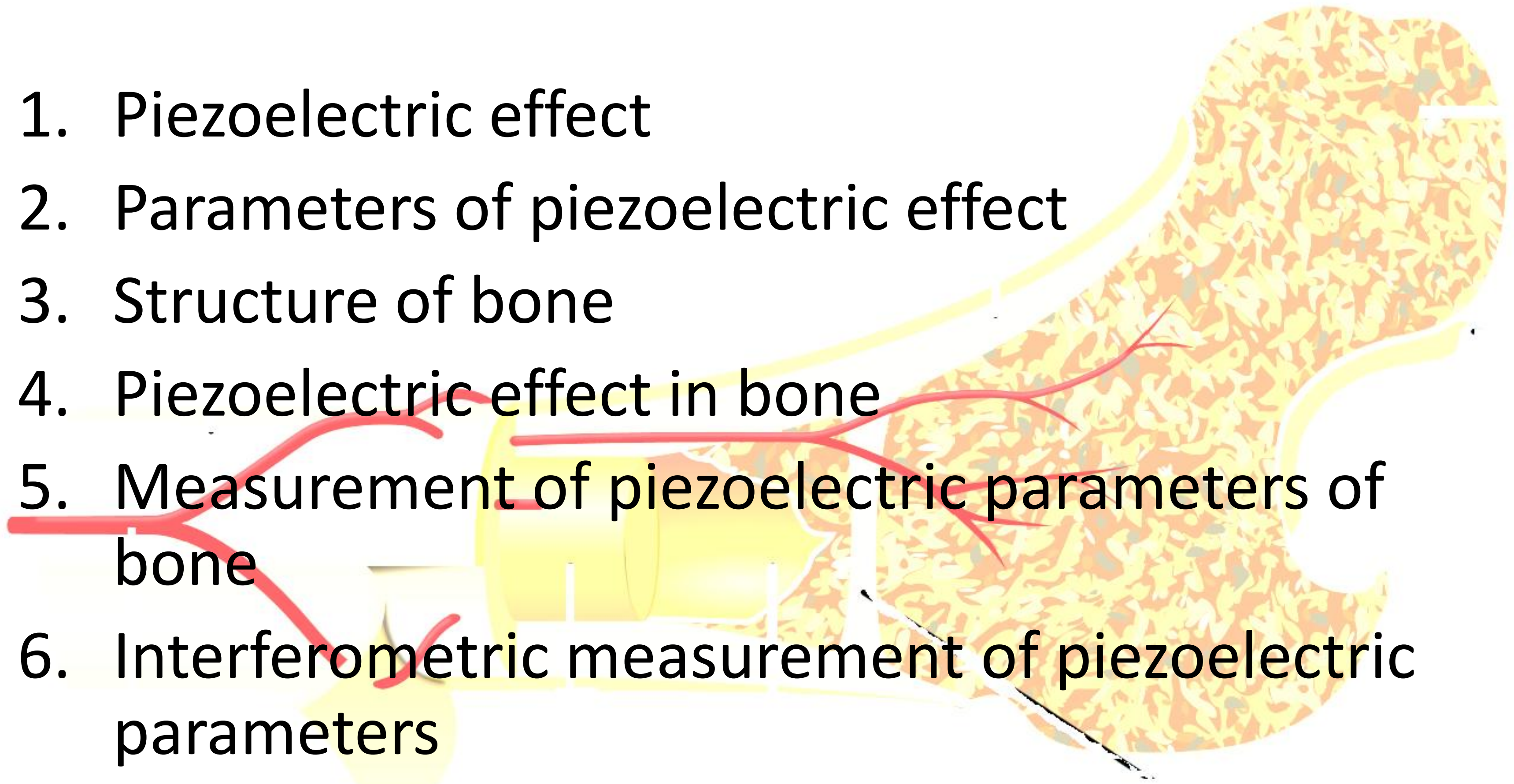
Piezoelectricity



1. Piezoelectric effect
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Piezoelectric effect

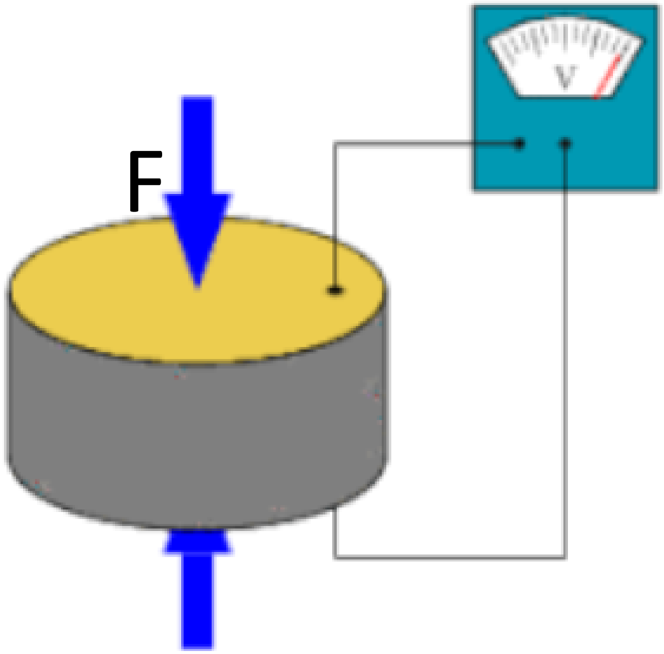
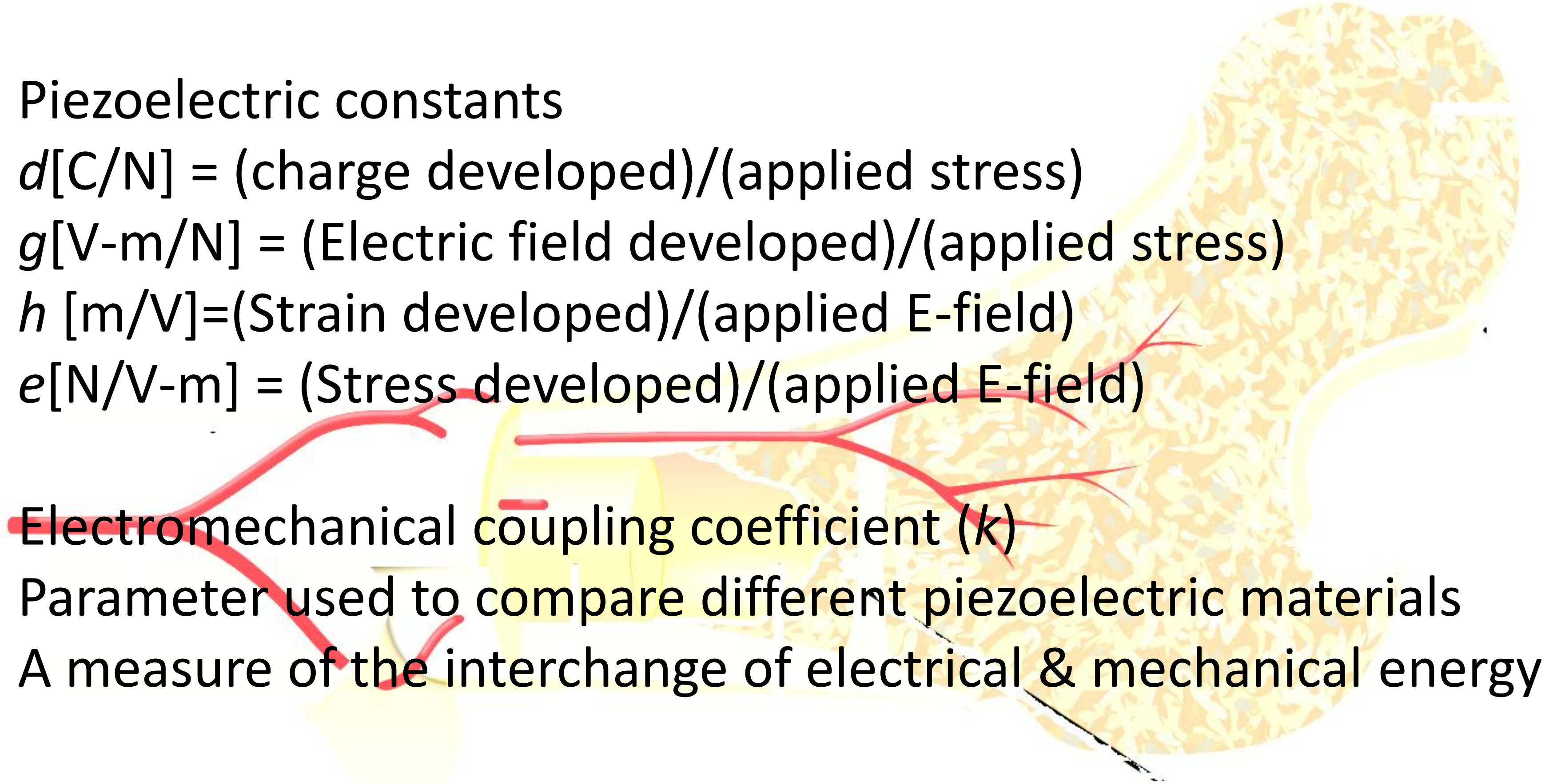


Fig. 1. A piezoelectric disk generates a voltage when deformed

The piezoelectric effect results from the linear electromechanical interaction between the mechanical and electrical states in crystalline materials with no inversion symmetry. The piezoelectric effect is a reversible process: materials exhibiting the piezoelectric effect (the internal generation of electrical charge resulting from an applied mechanical force) also exhibit the reverse piezoelectric effect, the internal generation of a mechanical strain resulting from an applied electrical field.

https://en.wikipedia.org/wiki/Piezoelectricity

Parameters of piezoelectric effect



Piezoelectric constants
d[C/N] = (charge developed)/(applied stress)
g[V-m/N] = (Electric field developed)/(applied stress)
h [m/V]=(Strain developed)/(applied E-field)
e[N/V-m] = (Stress developed)/(applied E-field)

Electromechanical coupling coefficient (*k*)
Parameter used to compare different piezoelectric materials
A measure of the interchange of electrical & mechanical energy

http://www.pitt.edu/~qiw4/Academic/MEMS1082/Lecture%208-1.pdf

Structure of bone

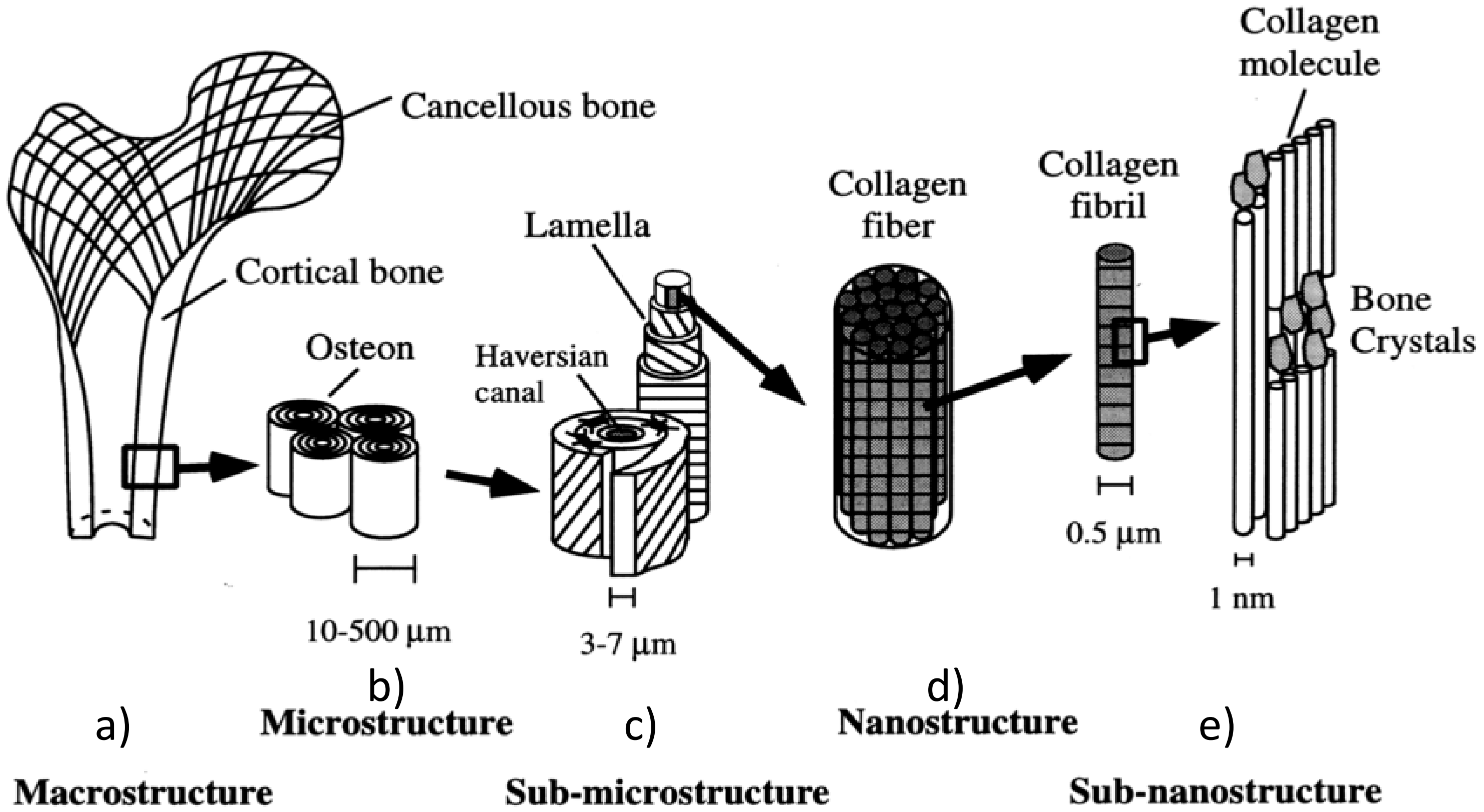


Fig. 2. Hierarchical structural organization of bone:(a) cortical and cancellous bone; (b) osteons with Haversian systems; (c) lamellae; (d) collagen fiber assemblies of collagen fibrils; (e) bone mineral crystals, collagen molecules, and non-collagenous proteins

The piezoelectric properties of bone are generally attributed to collagen fibrils

Rho, Jae-Young, Kuhn-Spearing, Liisa and Zioupos, Peter. *Mechanical properties and the hierarchical structure of bone.* Medical Engineering and Physics 20. 1998, p. 92-102.

Piezoelectric effect in bone

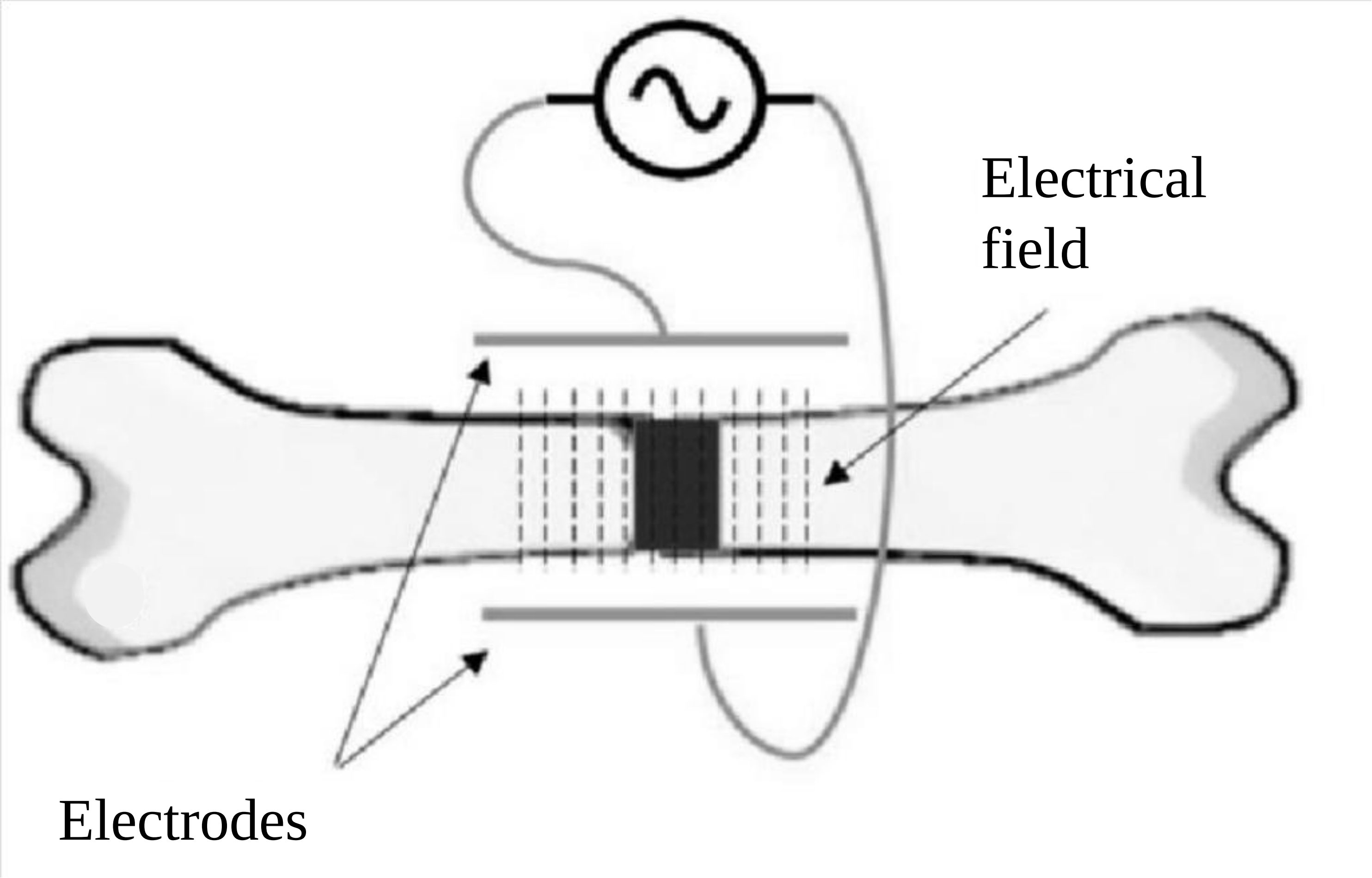
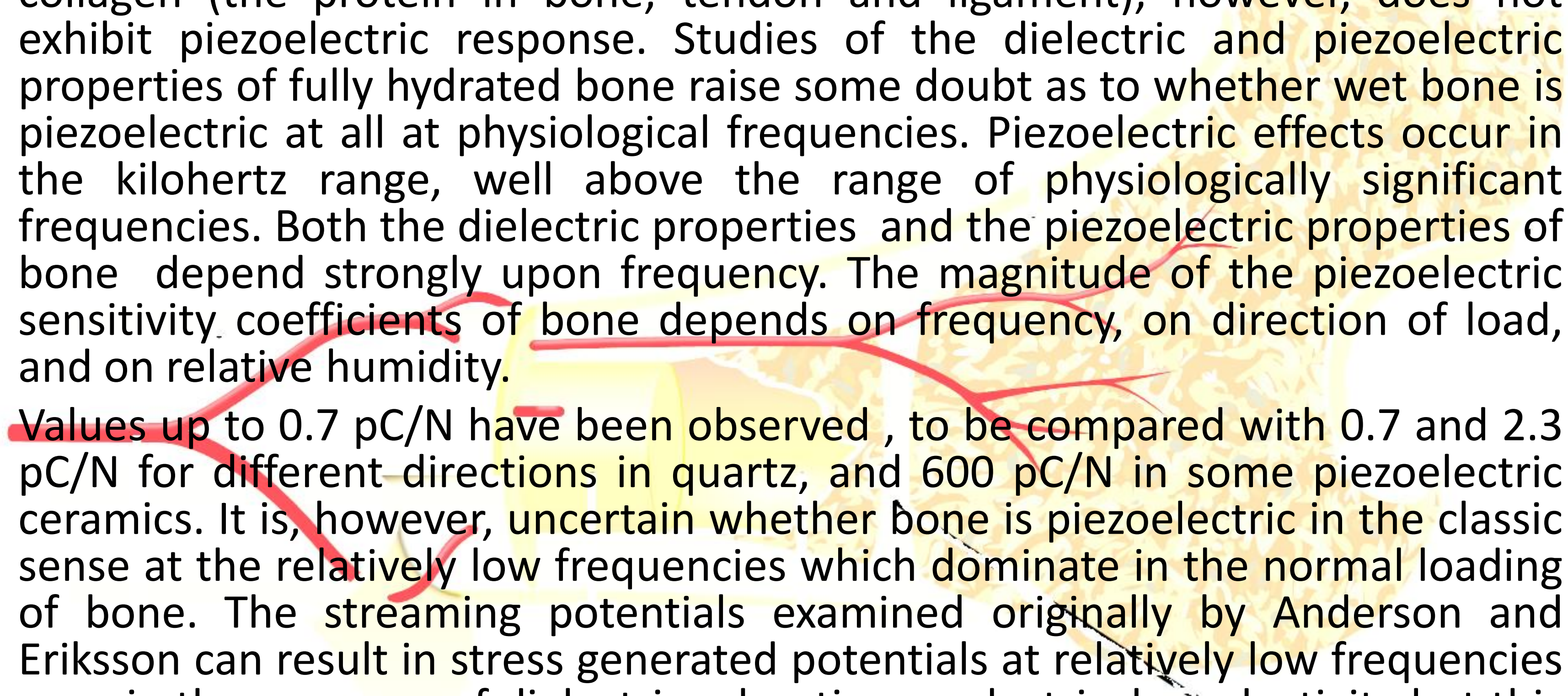


Fig.3. Electrical stimulation of bone healing diagram

https://www.semanticscholar.org/paper/Electrical-Stimulation-and-Bone-Healing%3A-A-Review-Khalifeh-Zohny/53702bd1799972a7f0040dca8e05885812ccd484

Measurement of piezoelectric parameters of bone



Fukada and Yasuda first demonstrated that dry bone is **piezoelectric** in the classic sense, i.e. mechanical stress results in electric polarization. Wet collagen (the protein in bone, tendon and ligament), however, does not exhibit piezoelectric response. Studies of the dielectric and piezoelectric properties of fully hydrated bone raise some doubt as to whether wet bone is piezoelectric at all at physiological frequencies. Piezoelectric effects occur in the kilohertz range, well above the range of physiologically significant frequencies. Both the dielectric properties and the piezoelectric properties of bone depend strongly upon frequency. The magnitude of the piezoelectric sensitivity coefficients of bone depends on frequency, on direction of load, and on relative humidity.

Values up to 0.7 pC/N have been observed , to be compared with 0.7 and 2.3 pC/N for different directions in quartz, and 600 pC/N in some piezoelectric ceramics. It is, however, uncertain whether bone is piezoelectric in the classic sense at the relatively low frequencies which dominate in the normal loading of bone. The streaming potentials examined originally by Anderson and Eriksson can result in stress generated potentials at relatively low frequencies even in the presence of dielectric relaxation or electrical conductivity but this process is as yet poorly understood.

http://silver.neep.wisc.edu/~lakes/BoneElectr.html

Interferometric measurement of piezoelectric parameters

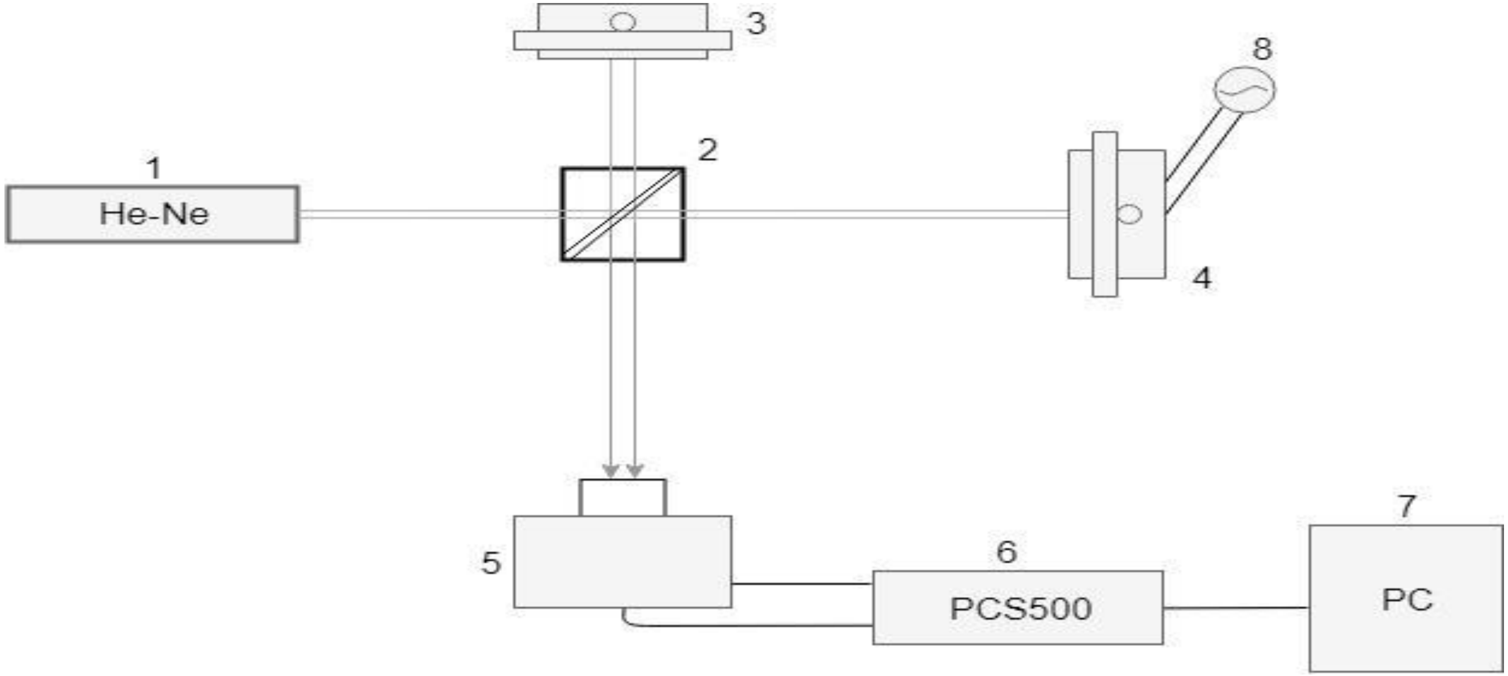


Fig. 4. Diagram of applied Michelson interferometer; 1 is laser, 2 is light beam divider, 3 is stable mirror, 4 is mirror with piezo-material, 5 is photo-sensor, 6 is oscilloscope block, 7 is personal computer, 8 is source of variable electrical voltage

Interferometric measurement of piezoelectric parameters

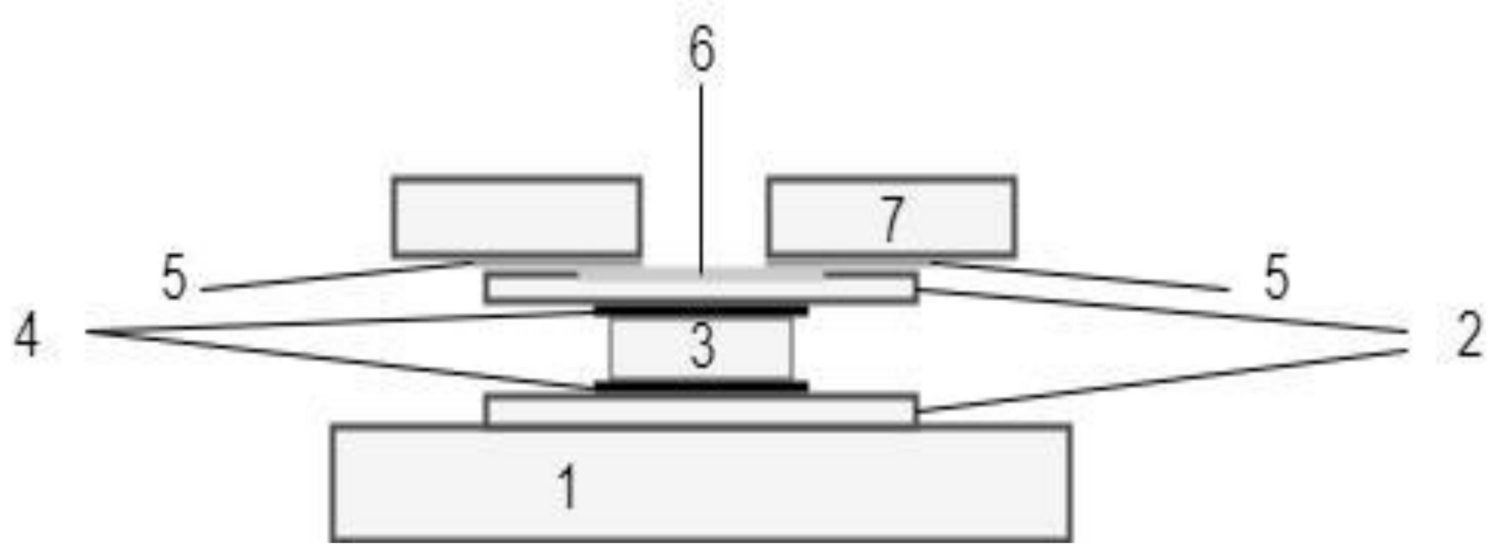


Fig. 5. Piezo-material attachment unit: 1 is- base; 2 are Teflon layers (PTFE film); 3 is piezo-material; 4 are electrodes; 5 is rubber layer; 6 is mirror; 7 is the oppressor

Interferometric measurement of piezoelectric parameters

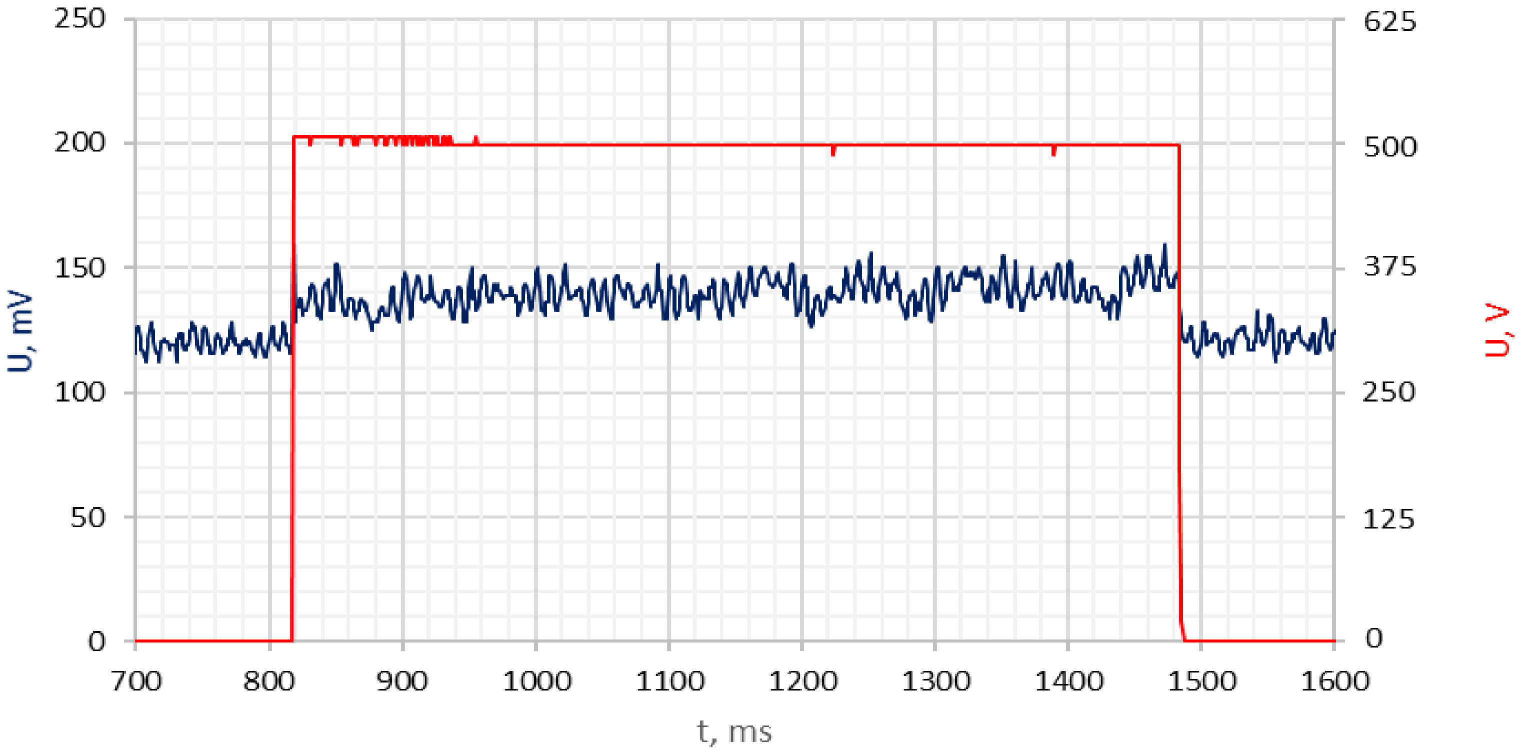
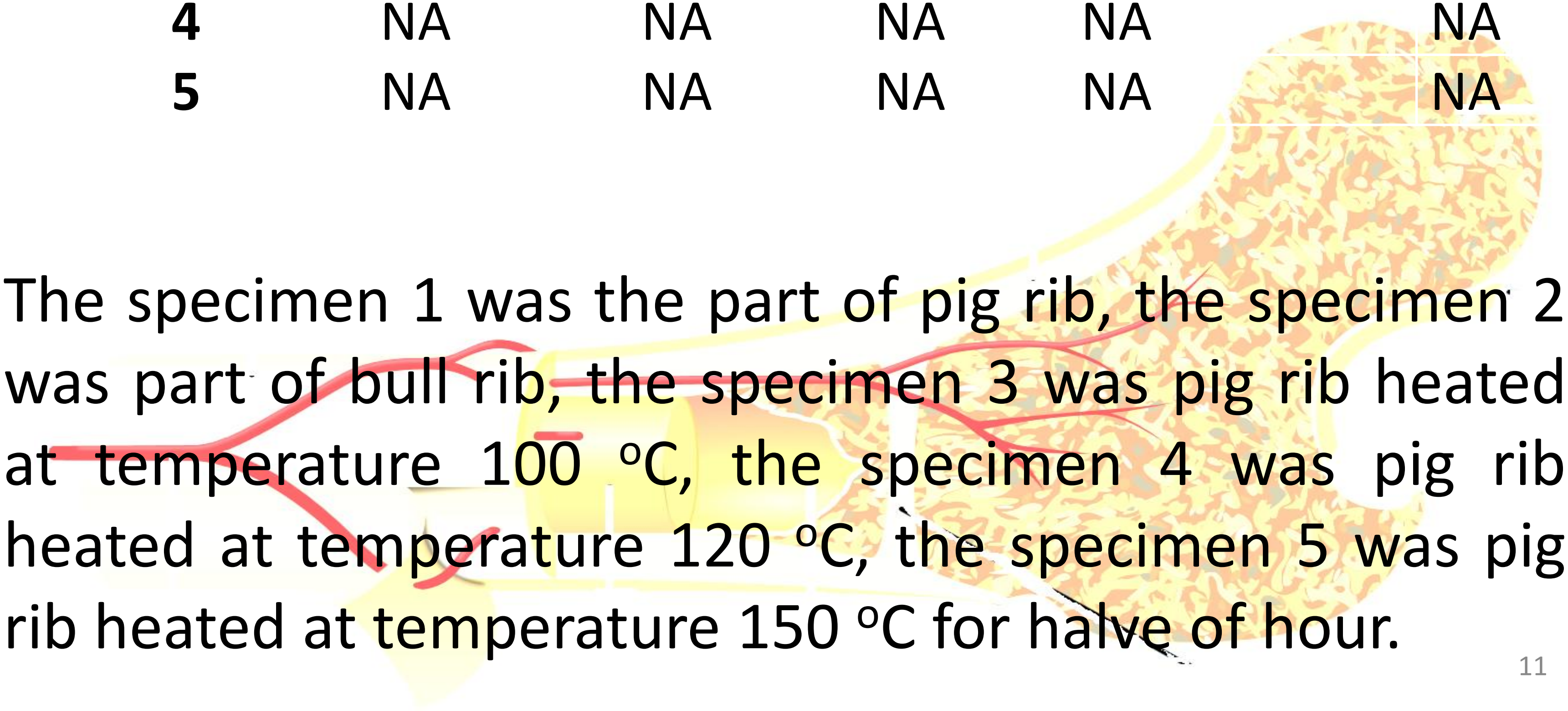


Fig. 6. Typical oscilloscope curves obtained in experiment: rectangular curve shows change of applied voltage to piezo-electric material; noisy curve means electrical signal from photodiode

Results of measurements

Piezoelectric parameters of specimens.

Speci-men	**Δh, nm**	**d_{33}, pm/V**	**ε_r**	**F, N**	**E, GPa**
1	15	30	95	174	8
2	40	80	65	100	9
3	30	50	100	130	3
4	NA	NA	NA	NA	NA
5	NA	NA	NA	NA	NA



The specimen 1 was the part of pig rib, the specimen 2 was part of bull rib, the specimen 3 was pig rib heated at temperature 100 °C, the specimen 4 was pig rib heated at temperature 120 °C, the specimen 5 was pig rib heated at temperature 150 °C for halve of hour.

Conclusions

The piezoelectric coefficients were slightly higher than those of other authors. This may be due to the absence of electrical charge leakage when measured by the reverse piezoelectric effect and no reduction of electric field influence on the piezoelectric material lattice.

Specimens heated at temperatures higher than 100 ^{o}C show no piezoelectric effect.

Similar results were obtained by scientists who studied thermally affected tendons and bones. Fukada first examined the tendons (composed of pure collagen) heated at various temperatures and found that collagen thermal contraction occurred above 120 ° C and measurements were no longer possible .

Other experiments on the dependence of the piezoelectric phenomenon on heating at higher temperatures by Fukada and Hara showed that this phenomenon disappeared when the samples were heated above 150 °C. This temperature irreversibly changes the structure of collagen in the bone .

Changes of piezoelectric parameters after ionizing radiation should be investigated in the future.