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1. (4 points) As a result of a phase transition, a crystal of the 422 symmetry loses all elements of point symmetry except for the 2-fold axis marked with 'A' in Fig.1. Find the variation in the dielectric constant tensor caused by this phase transition. For the presentation of this tensor, use the crystallographic reference frame corresponding to symmetry 422 (shown in the Fig. 1). The information from the table of K-tensors can be used (if needed) without additional justification.

What change of the symmetry of the dielectric response is induced by this transition?
Find the K-tensor structure in the reference frame of Fig. 1

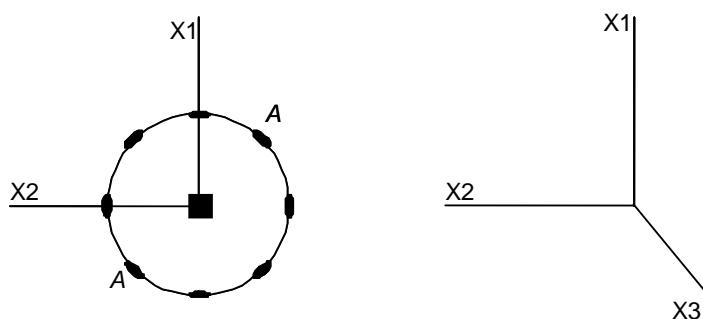


Fig.1. Symmetry elements of the 422 point group and corresponding reference frame

2. (4 points) The piezoelectric coefficient d_{11} of quartz (symmetry 32) is measured using a setup where the plates of the capacitor are parallel to (100) plane of the crystal (as shown in Fig.2). The sample can freely expand in X2 and X3 directions as shown in Fig.2. The measurements are done twice: under isothermal and under adiabatic conditions. Will be any differences between the results of the measurements?

The information from all tables of the course can be used without additional justification.

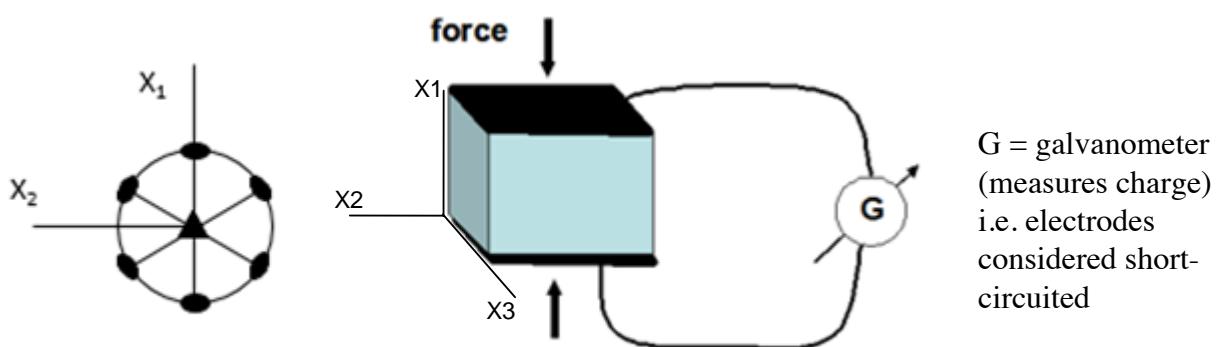


Fig.2. Experimental setup used for piezoelectric coefficient measurements.

3. (5 points) The piezocaloric effect is measured in a sample of BaTiO₃ (symmetry **4mm**, the 4-fold axis is directed along x_3 direction). The experimental setup is shown in Fig.3. The surfaces of the sample are under open circuit condition, the sample can freely expand in x_1 and x_2 directions, there is no heat exchange with the environment. Initial temperature of the sample is 300 K.

Determine the change of the temperature at application of pressure 100 MPa in x_3 direction. Use the numerical values for BaTiO₃ from the table below (x_3 axis is directed along the 4-fold symmetry axis). The information from all tables of the course can be used without additional justification.

s_{11}	$8.05 \times 10^{-12} \text{ m}^2/\text{N}$	d_{15}	$392 \times 10^{-12} \text{ C/N}$
s_{12}	$-2.35 \times 10^{-12} \text{ m}^2/\text{N}$	d_{31}	$-35 \times 10^{-12} \text{ C/N}$
s_{13}	$-5.24 \times 10^{-12} \text{ m}^2/\text{N}$	d_{33}	$86 \times 10^{-12} \text{ C/N}$
s_{33}	$15.7 \times 10^{-12} \text{ m}^2/\text{N}$	K_{33}	150
C	$2.42 \times 10^6 \text{ J}/(\text{m}^3 \cdot \text{K})$	p_3	$-5 \times 10^{-4} \text{ C}/(\text{m}^2 \cdot \text{K})$
α_3	$3.5 \times 10^{-5} \text{ 1/K}$	ε_0	$8.85 \times 10^{-12} \text{ F/m}$

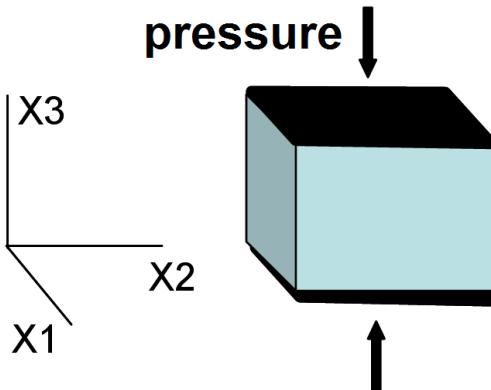


Fig.3. Experimental setup used for piezocaloric effect measurements.

4. (5 points) The impact of mechanical conditions on the electro-caloric effect is investigated. The (001) surfaces of the parallelepiped BaTiO_3 sample in its tetragonal phase $4mm$ (4-fold symmetry axis is directed along the x_3 axis) are covered with electrodes (Fig.3), the voltage is applied, and the change of the sample temperature is measured. The sample is thermally isolated (adiabatic conditions).

In measurement **(a)**, the sample is kept mechanically free.

In measurement **(b)**, the sample is kept mechanically free in x_1 and x_2 directions, while the distance between electrodes L is forced to not change.

In cases **(a)** and **(b)**, will the temperature of the sample increase or decrease? In which case the change of temperature is larger?

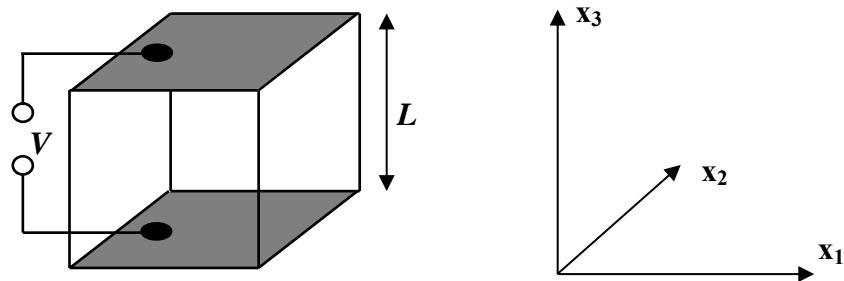


Fig.4. BaTiO_3 sample for electro-caloric effect measurements.

- Use reference data from the previous exercise if needed