What Governs the Two Experiments Is Not Two Coefficients but One

— in quartz, 1 N gives 2.300000 pC and 1000 V gives 2.300000 nm, from one and the same d — the separator is whether two coefficients are needed or one is enough — [Paper 666]

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— From thinking to syncing. —

Abstract

A piezoelectric has two faces: squeeze it and charge appears, apply a voltage and it stretches. They look like separate phenomena, so they look as if they need separate coefficients.That both are written with one and the same number, and what would follow if they were not, are counted.No new theorem or law is claimed. First, one number governs both experiments——in quartz ($d = 2.300000 \times 10^{-12}$ C/N), a force of 1 N produces 2.300000 pC of charge and a voltage of 1000 V produces an extension of 2.300000 nm (Section 2). **Second, and this is the core. If the coefficients differed, energy would appear from nowhere——taking a force of 1 N and a voltage of 1000 V around a closed path, the cross term gives 2.300000×10^{-9} J on the direct side and on the converse side alike. Were they a tenth apart, each round trip would leave 2.300000×10^{-10} J behind** (Section 3). **Third, how strongly the two are coupled is another quantity——the electromechanical coupling factor is 0.102246 for quartz and 0.670020 for PZT. The ratio in d itself is 162.608696, but in the square of the coupling factor it is only 42.942221** (Section 2). **Fourth, a large d is not by itself an advantage——PZT stretches 162.608696 times as far as quartz under the same voltage, but being softer and of higher permittivity, its coupling does not follow that ratio** (Section 2). **Fifth, the same plate wears a different face depending on which side is measured——a quartz plate 0.1 mm thick resonates at 1.660000×10^{7} Hz and one 0.3 mm thick at 5.533333×10^{6} Hz, the same d serving both to drive and to detect** (Section 3). **Sixth, the separator is whether two coefficients are needed or one is enough——that one number suffices for two experiments can be checked by measurement, because otherwise a round trip yields work** (Section 4).
Keywords: piezoelectric effect, converse piezoelectric effect, piezoelectric coefficient, Onsager reciprocity, electromechanical coupling factor, quartz.

Scope of this paper (scope note): **No new theorem or law is claimed——the direct and converse piezoelectric effects, their being governed by the same coefficient, Onsager's reciprocal relations (Onsager 1931), and the definition of the electromechanical coupling factor are all standard (Cady 1946).Tensor components are not counted——how many independent components a crystal symmetry leaves is not the subject. Only one direction is examined.Large signals are not treated——poling, hysteresis, nonlinearity and fatigue are not included. Only the linear range is examined.No device is designed——oscillator circuits, matching and packaging are not entered into (the same line as Paper 336).Representative values are used——the coefficients, elastic compliances and relative permittivities of quartz and PZT are representative, not measurements of particular samples.Relation to earlier papers**: **Paper 336 counted the number 32768 inside a wristwatch and stated that it would not build the physics of quartz, leaving the piezoelectric effect, the tuning-fork modes and the quadratic temperature curve untouched——this paper takes that seat.Paper 143 showed that minimum entropy production is not a principle but a theorem with a fence, and placed Onsager's reciprocal relations as that fence——here that reciprocity appears as one measurable coefficient.**What is added is **setting the direct and converse effects side by side as numbers from one d, deriving how much work a round trip would yield if they disagreed, showing that the ratio in d and the ratio in coupling are different**, and **placing the separator on two coefficients versus one**.

1. Notation and the Question

Setting: **apply a force F to a piezoelectric and a charge Q appears; apply a voltage V and its length changes by x. Naively each experiment has its own coefficient.**

$$Q = d_{\text{direct}} F, \qquad x = d_{\text{converse}} V$$

Thermodynamics says the two must be the same number. Here they are set side by side as experimental quantities, and what would follow from a disagreement is examined.

Question: **to write the two experiments, are two coefficients needed, or is one enough?**

2. One Number Governs Both

Computation 2.1: **the size of the direct and converse effects was derived for quartz and PZT.**

material	d (C/N)	charge from 1 N	extension from 1000 V
quartz	2.300000×10^{-12}	2.300000 pC	2.300000 nm
PZT	3.740000×10^{-10}	374.000000 pC	374.000000 nm

The numbers on the left and right are the same. Only the units differ; one d sets both.

Computation 2.2: **the electromechanical coupling factor, the share of the work put in that is passed to the other form, was derived: for quartz 0.010454 squared, 0.102246 as a factor; for PZT 0.448926 and 0.670020.**

> **Observation 2.3**
>
> **a large d is not by itself an advantage.The d of PZT is 162.608696 times that of quartz, and yet the ratio of the squared coupling factors is only 42.942221——d sets the size of the displacement, while the share that transfers is d divided by the elastic compliance and the permittivity. One symbol cannot speak for both.**

3. If They Differed, Energy Would Appear

Computation 3.1: **the cross term of the work under a force of 1 N and a voltage of 1000 V was derived on the direct side (dFV) and on the converse side (dVF). Both give 2.300000×10^{-9} J, with a difference of 0.**

Computation 3.2: **supposing the direct coefficient alone were a tenth larger, each round trip of force and voltage would leave 2.300000×10^{-10} J behind.**

> **Observation 3.3**
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> **this is the core: reciprocity is another way of saying that nothing appears.If the two coefficients differed, a closed path of applying force, applying voltage and returning would leave work behind, and that work came from nowhere——so the two must be equal. This is not a statement about measurement accuracy but about the closing of a round trip.**

Computation 3.4: **the same plate resonates through its thickness: 1.660000×10^{7} Hz for a quartz plate 0.1 mm thick and 5.533333×10^{6} Hz for one 0.3 mm thick.**

> **Observation 3.5**
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> **one coefficient serves both to drive and to detect.Shaking it with a voltage and taking a voltage from the shaking are the same d——which is why one plate can be both the driver and the sensor.**

4. The Separator

Observation 4.1

the separator is whether two coefficients are needed or one is enough.If two were needed, the direct and converse values could be measured independently and could disagree. If one is enough, measuring either settles the other——allowing a disagreement yields 2.300000×10^{-10} J per round trip, so the side where one is enough is the right one.

Observation 4.2

beside Paper 143.Paper 143 showed that minimum entropy production is a theorem only inside the fence of Onsager reciprocity——the d here is one case where that fence shows up as a measurable number. The fence is not an abstraction; it can be checked with 1 N and 1000 V.

Observation 4.3

what is not said.Counting tensor components from crystal symmetry, poling, hysteresis and device design are not treated; the line drawn by Paper 336 is kept——what is shown is that one number suffices for two experiments, and that in a world where it did not, work would appear.

5. Roll Call and Closing

1. **2.300000 pC from 1 N** (Computation 2.1): **the direct effect.**
2. **2.300000 nm from 1000 V** (Computation 2.1): **the converse; the same d.**
3. **the cross terms agree exactly** (Computation 3.1): **a difference of 0.**
4. **a tenth apart gives 2.300000×10^{-10} J** (Computation 3.2): **the core.**
5. **quartz couples at 0.102246** (Computation 2.2): **the share transferred.**
6. **PZT at 0.670020** (Computation 2.2): **softer, higher permittivity.**
7. **d differs by 162.608696** (Observation 2.3): **the displacement is larger.**
8. **the square differs by 42.942221** (Observation 2.3): **one symbol, two things.**
9. **1.660000×10^{7} Hz at 0.1 mm** (Computation 3.4): **drive and detect, one d.**

10. **two or one** (Observation 4.1): **the separator; Papers 143 and 336.**

Closing: **Force into charge, voltage into motion: the two directions look like separate phenomena.Yet in quartz $1\ \mathrm{N}$ gives $2.300000\ \mathrm{pC}$ and $1000\ \mathrm{V}$ gives $2.300000\ \mathrm{nm}$, and one coefficient has sufficed.Were the direct and converse a tenth apart, a single round trip of force and voltage would leave $2.300000 \times 10^{-10}\ \mathrm{J}$ behind——reciprocity is nothing other than the statement that this round trip closes.The separator is whether two coefficients are needed or one is enough.Placed among the earlier papers——the Onsager reciprocity that Paper 143 placed as a fence appears here as one number checkable with $1\ \mathrm{N}$ and $1000\ \mathrm{V}$, in the seat Paper 336 left open.To be honest——only the linear range and representative values were treated, and the size of the coupling factor does not decide which material is better.**

References

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