Effects of Temperature and Morphology on Piezoelectricity in Crystalline Sucrose

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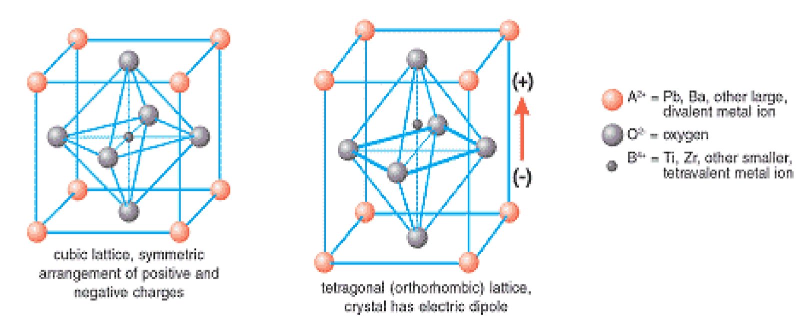
Abstract

While the factors affecting piezoelectricity have been well studied in multiple piezoelectric materials, there has not yet been a study on the factors affecting piezoelectricity in crystalline sugar. In this experiment, we explore the effects of temperature and crystal morphology on the piezoelectric effect in crystalline sugar. We attempted synthesis of crystals with two methods, in wells and on dowels. We also used commercially grown crystals for testing. These crystals were subjected to consistent pressures and a temperature range from -50° C to 50° C, and their voltage responses were recorded. In these tests, we determined that there is a positive correlation between increasing temperature and piezoelectric resonse, with the response going to 0 beyond the temperatures at the ends of our range. It is also of interest to note that the typical crystal growing method failed, while the discs produced crystals with structure nearly identical to the commercial crystal.

Introduction

Piezoelectricity is the production of an voltage upon mechanical stress of a material. This effect can also go the other way, i.e. an electric current running through a piezoelectric material will produce a change in shape of the material. This effect is manifested due to shifts in charge distribution within a crystal lattice. A mechanical stress, for example, pushes the atoms in the lattice out of alignment. This results in an overall charge imbalance across the material, producing a voltage. An applied voltage, on the other hand, will cause the material to shift in order to rebalance the charges.[1] Examples of materials that exhibit piezoelectric characteristics include quartz, Rochelle salt, and lead titanate. These materials have been well characterized.[2,3,4]



Mechanism of piezoelectricity[5]

Along with these materials, several sources note that crystalline sucrose is also piezoelectric.[1] However, we have found no work investigating the factors affecting piezoelectricity of crystalline sucrose. Therefore, we set out to explore the effects of temperature extremes and crystal morphology (single crystal vs. crystal aggregate) on the piezoelectric response of sucrose crystals. There are consistent trends across previous work done on piezoelectric materials; therefore, it was expected that there would be likely a linear correlation between piezoelectric response and temperature, with a drop to 0 at extreme temperatures.

Methods

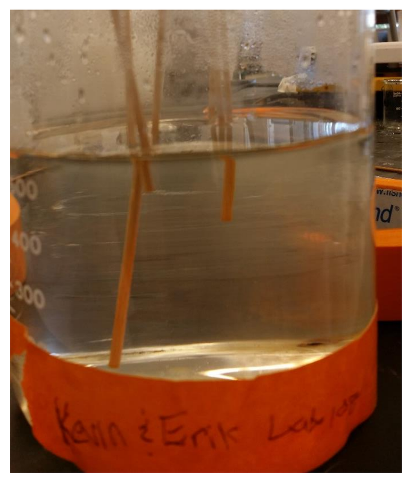
Synthesis
- Commercial singles
- Large aggregates
- Crystal discs

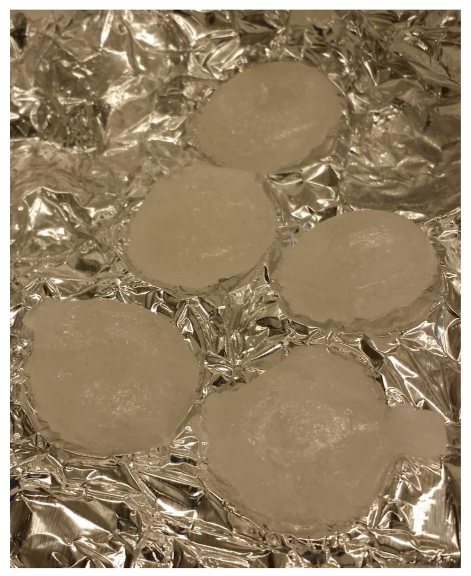
→ **Microscopy** →

Testing
- Room temperature
- Cold tests
- Hot tests

Synthesis

1. Single crystals were obtained commercially, as these proved too difficult to grow given our constraints
2. Aggregate formation was attempted using a slow growth method. Boiling water was supersaturated with sucrose. Dowels were placed into the beaker at varying depths in hopes of attaining different sizes and shapes of crystal aggregate. The beaker was placed in an insulated container and partially covered with Parafilm to allow for slow cooling and slow evaporation. This was left for several days in a lab drawer.
3. Small discs of crystal were grown by placing solution into aluminum foil covered wells. Some of the saturated sucrose solution was drawn from the beaker and poured into each well. Crystalline sucrose (~1 mm³) was then placed the wells as seed crystals. This tray was then also placed into a lab drawer for several days to grow.





From left to right:
Single crystal,
aggregate growth with dowels,
crystal disc

Testing

First, tests were run to confirm that crystalline sucrose piezoelectric properties. Clips were attached to opposite ends of the crystals, and we observed the voltage across each crystal as we applied consistent pressures. (Fig 1) This was measured using Vernier LabQuest with differential voltage meter.

Fig 1: Experimental setup

Temperature testing used the same procedure as the room temperature tests, with the addition of adjusting the temperature of the crystals. For the cold testing, we used dry ice and liquid nitrogen to achieve temperature of -10° C and -50° C, respectively. For hot testing (up to 50° C), we placed the crystals in a sand bath that was around 200° C. Precise temperatures were taken using a thermocouple- the crystal was taken out of the extreme temperature environment, and the probe was pressed into the crystal until the temperature equilibrated. The volume of each crystal was measured using heptane displacement.

Results and Observations

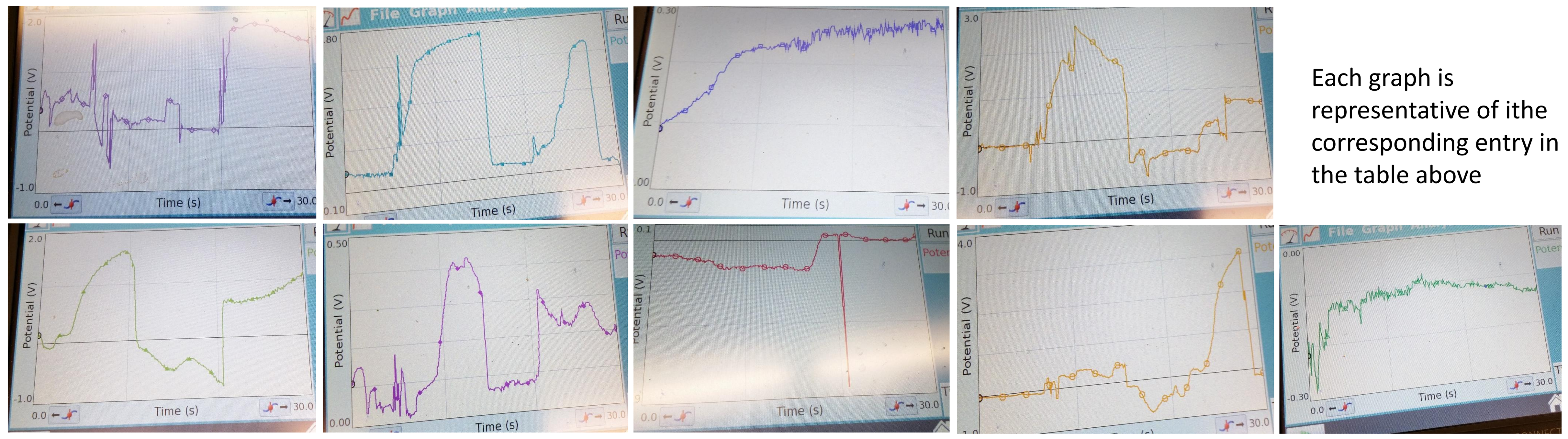
Synthesis

- The aggregate growth was not successful. It appears the sucrose crashed out of solution, and formed a mixture of hardened solution with small crystals embedded throughout. This was confirmed under by microscopy.
- The discs worked well. Their morphology, both macroscale and microscale, appear to correlate very well to typical crystal morphology (regular geometry) as well as to the commercially grown single crystal.

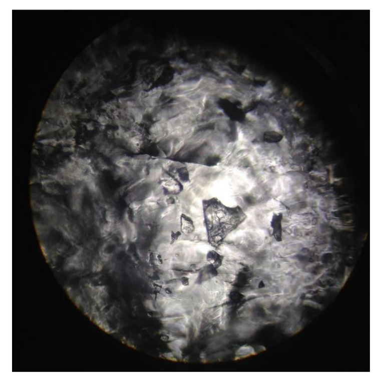
Testing

- We observed a positive correlation between temperature and piezoelectric response. We also observed generally higher response from the discs as opposed to the single crystals. We see not only lower voltages at low temperatures, but also smaller peaks. We see no correlation between pressure and voltage at the temperature extremes.

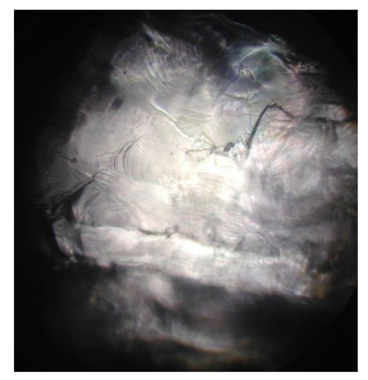
-Average values reported -Values in V/cm^{-3}, error of ± .50% due to tolerance of graduated cyliner Peak response= $(\lvert V_{max}\rvert - \lvert V_{min}\rvert)$/volume at time of pressure *discs broke when heated	Peak response at room temperature (24° C)	Peak response at -10° C	Peak response at -50° C	Peak response at 30° C	Peak response at 50° C
Discs	2.0	.9	~0	2.9	*
Commercially grown	1.4	.4	.1	2.5	~0



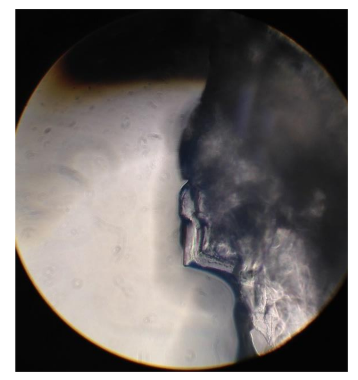
Each graph is representative of ithe corresponding entry in the table above



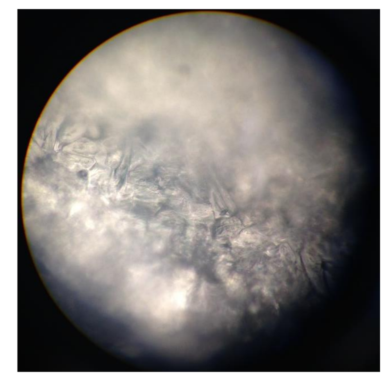
Single crystal, 100x



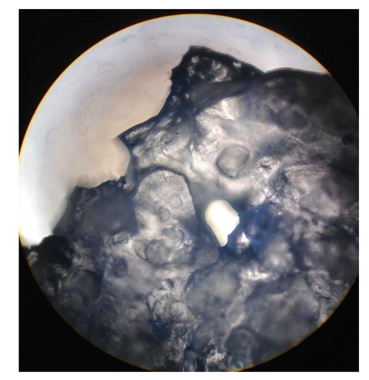
Single crystal, 1000x



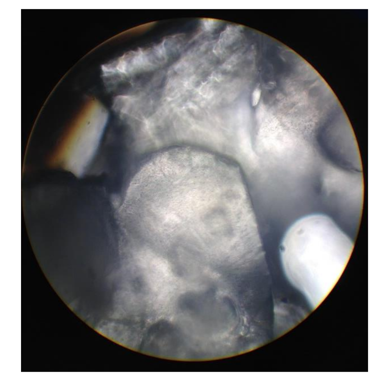
Disc, 100x



Disc, 1000x



Aggregate, 100x



Aggregate, 1000x

Discussion and Conclusions

In these experiments, we've shown that there is a positive response of piezoelectric response to mechanical stress at room temperature. However, when the crystal was subjected to extreme temperatures, there was almost no correlation between applied pressure and change in voltage, indicating an extinction of the piezoelectric effect at these temperatures. The experiment is parallel to the experiment done by R Wolf and Trolier where lead ziconate titanate (a material with piezoelectric properties) led to the same conclusion as our experiment. There is good potential for future work. For example, the alligator clips of the electrode were not the best instrument to use in this sort of experiment since the sugar samples made were too big and fragile. In addition, these clips were not able to maintain a very solid grip on the crystals. Given ideal parameters including better equipment and synthesized samples, we would like to either test our methods on other materials with piezoelectric effects, or be able to quantify the applied pressure.

Acknowledgements and References

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