Ferroelectric Effects of $BaTiO_3$

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An electric potential ranging from 7 to 10 V was applied to a sample of crystalline Barium Titanate ($BaTiO_3$) to raise the samples temperature from 30^oC to 140^oC. After calculations, we deduced that $BaTiO_3$'s Curie temperature is 103.65 ± 0.65. This does NOT agree with previously published experiments for $BaTiO_3$'s Curie temperature of 120^oC.

I. INTRODUCTION

A 3D lattice is a 3 dimensional structure of points called lattice points that can be used to model the periodic structure of crystals. Associated with a lattice are translation vectors, say τ_1, τ_2, τ_3 such that any vector connecting two lattice points is a (integer) linear combination of the translation vectors. Mathematically, a lattice must be invariant under rotations and reflections about a lattice point. This condition restricts the number of possible lattices types. For example, in the 2D case, a five-axis symmetry lattice is not possible [1]. There are a total of 14 possible lattices types (also called Bravais lattices). Each type is characterized by their edge lengths a, b, c and the angles between them α, β, γ. The edge lengths need not be the same as the magnitude of the translation vectors; but are multiples of the translation vectors magnitude.

The smallest cell possible containing the fundamental compound is called the *unit cell*. The unit cell is the parallelpiped with edge lengths a, b, c. A *primitive cell* is the parallelpiped constructed from translation vectors; it encloses exactly one lattice point. The unit cell may enclose more than one lattice point.

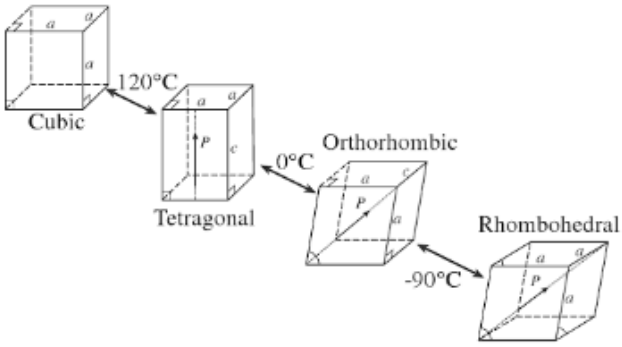


FIGURE 31.8 $BaTiO_3$ polymorphs showing direction of polarization.

FIG. 1: Structures

A. Theory

The 14 Bravais lattice's are categorized into 7 possible unit cells: cubic, tetragonal, monoclinic, orthorhombic, rhombohedral, hexagonal, and triclinic. $BaTiO_3$'s crystal structure depends on its temperature. They are listed as follows in increasing temperature order: body-centered rhomonhedral, orthorhombic, tetragonal, and cubic. As seen in Figure 1 [2], at room temperature $BaTiO_3$ has the tetragonal configuration. This is characterized by $\tau_1 = \tau_2 \neq \tau_3$ and $\alpha = \beta = \gamma = 90^o$.

The asymmetry of this structure is associated with a displacement of Ti^{4+} in the +z-direction. Where we choose the z-direction to be along the c edge. This displacement causes the unit cell to be polarized, resulting in spontaneous polarization. After some transition temperature T_c, $BaTiO_3$ transitions to a cubic structure which is symmetric and has virtually no polarization. By definition, $BaTiO_3$ a ferroelectric.

II. MATERIALS AND METHODS

A mounted, solid sample of Barium Titanate was used in conjunction with an AMREL linear power supply, Fluke 52k/J Therometer and a DMR-2322 Multimeter. After configuration of the wiring, shown in Fig 2, we turned on the multimeter, thermometer and power supply without the sample to record the capacitance of the wires. The sample was then connected and we started recording the multimeter reading in pF and the temperature of the sample in degrees Celsius. The initial voltage of the power supply was started at 7 and we increased it to 9.5 during the ascent to 146^oC. Similarly, on the descent back to temperatures under 50^oC, we changed the voltage in intervals in order for the sample and its temperatures to rise and fall at a consistent pace for the sake of data.

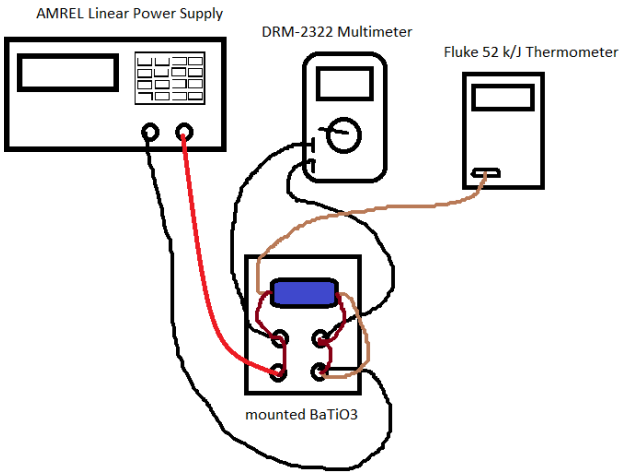
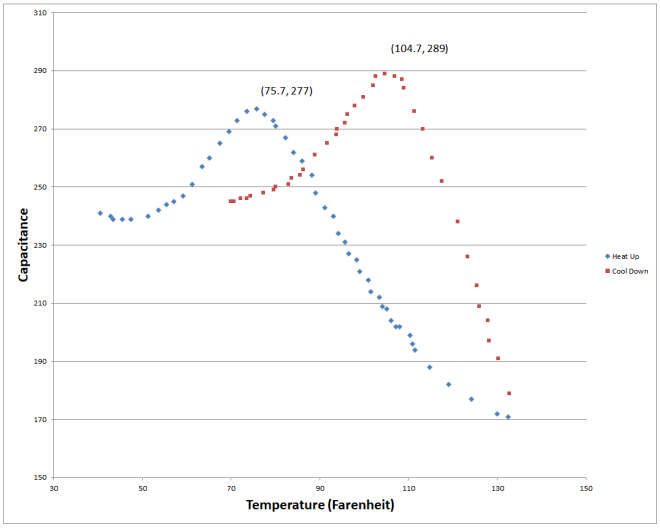


FIG. 2: Setup

FIG. 3: Run 1



III. DATA AND CALCULATIONS

We took two sets of data. The capacitance of our multimeter leads are:

1. Run 1 = $234pF$
2. Run 2 = $226pF$

The transition temperatures T_c are:

TABLE I: Run 1

	Temperature (^oC)	Capacitance (pF)
Heat Up	75.7	277
Cool Down	104.7	289

TABLE II: Run 2

	Temperature (^oC)	Capacitance (pF)
Heat Up	88.2	271
Cool Down	103.0	287

The heat up plot is to the left and the cool down to the right on our plots.

FIG. 4: Run 2

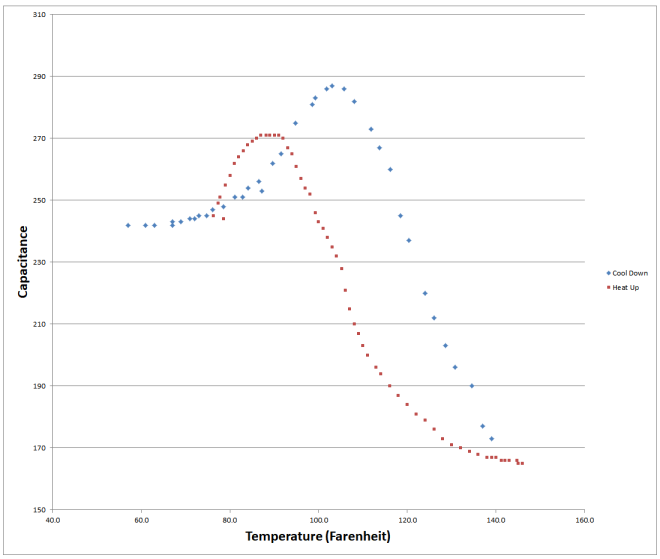
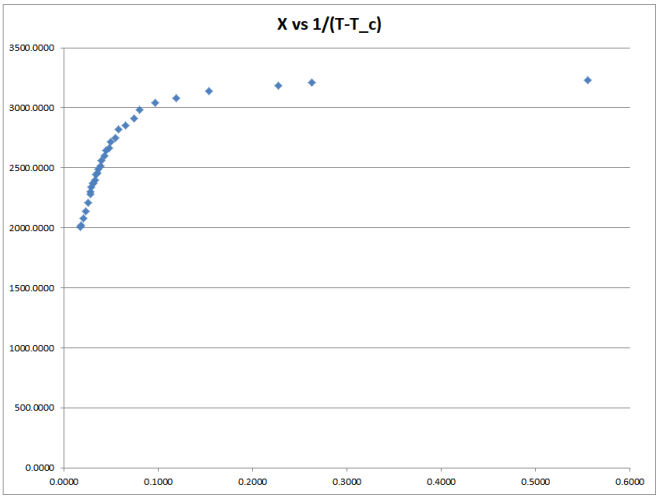


FIG. 5:



We tried to plot χ vs $\frac{1}{T-T_C}$ to get a linear plot but we did not (Fig 5).

IV. ERROR ANALYSIS

We take the averages of the data in Table III and Table IV.

TABLE III: Error Table 1

	Temperature (^oC)	Capacitance (pF)
Heat Up	81.95 ± 6.25	271 ± 3
Cool Down	103.65 ± 0.65	288 ± 1

Correcting for sig-figs:

TABLE IV: Error Table 2 - Sig-Figs

	Temperature (^oC)	Capacitance (pF)
Heat Up	81.9 ± 6.3	271 ± 3
Cool Down	103.6 ± 0.7	288 ± 1

V. CONCLUSION

Heating up $BaTiO_3$ shows us that it undergoes a phase transitions that changes it's crystal structure. The ferroelectric state indicated antisymmetry in it's structure and the paraelectric state indicates that it undergoes phase transition into a symmetric structure. We weren't able to show $BaTiO_3$ follows Curies Law possibly beacuse the heating wasn't uniform or that because it wasn't a perfect crystal. There might be impurities in the crystal in addition to the sample being comprised of domains.

VI. REFERENCES

[1]Charles Kittel *Introduction to Solid State Physics*. Addison-Wesley, 2005.
[2]Carter, C., Norton, M. *Ceramic Materials: Science and Engineering*. [*Section 31*]. (2007). New York; London: Springer.