

# INSTRUCTION MANUAL

## CURIE TEMPERATURE KIT (For Ferroelectric Materials)



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# CURIE TEMPERATURE KIT FOR FERROELECTRIC MATERIAL

## INTRODUCTION

Ferroelectric materials exhibit electric dipole moment even in the absence of an external electric field. Ferroelectric materials are of theoretical and technical interest as they have unusually high and unusual temperature dependent values of the dielectric constant, the piezoelectric effects etc.

Ferroelectricity usually disappears above a certain temperature called the transition (or Curie) temperature. Knowledge of the Curie temperature and the variation of the dielectric constant below and above the Curie temperature is of interest to the physicists and the engineers.

Probably the best-known ferroelectric material is barium titanate  $\text{BaTiO}_3$ ; it is a representative of the so-called oxygen octahedron group of ferroelectric materials. The reason for this name is that above the Curie temperature ( $\theta = 120^\circ \text{C}$ ),  $\text{BaTiO}_3$  corresponds to the cubic structure presented in Fig. 1. In this structure, the  $\text{Ba}^{2+}$  ions occupy the corners of a cube; the centers of the cube faces are occupied by  $\text{O}^{2-}$  ions. The oxygen ions form an octahedron, at the center of which the small  $\text{Ti}^{4+}$  ion is located. The  $\text{Ti}^{4+}$  ion is considerably smaller than the space which is available inside the oxygen octahedron. It thus brings with it a high ionic polarizability for two reasons: (a) it has a charge of  $4e$  and, (b) it can be displaced over a relatively large distance. This may be the explanation for the occurrence of spontaneous polarization in  $\text{BaTiO}_3$ .

There is an intimate relationship between the ferroelectric properties and the atomic arrangement in ferroelectric materials. Above  $120^\circ \text{C}$ ,  $\text{BaTiO}_3$  has the cubic structure indicated in Fig. 1. When the temperature is lowered through the critical temperature of  $120^\circ \text{C}$ , the material becomes spontaneously polarized and at the same time the structure changes. The direction of spontaneous polarization may lie along any of the cube edges, giving total 6 possible directions for the spontaneous polarization. Along the direction of spontaneous polarization of a given domain, the material expands, whereas perpendicular to the polarization direction it contracts. Thus, the material is no longer cubic, but corresponds to a so-called tetragonal structure.

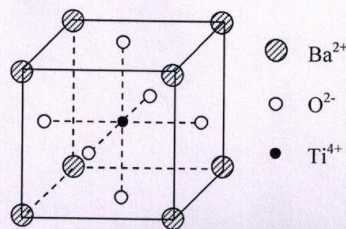


FIGURE 1

## THEORY

In this experiment an LC circuit is used to determine the capacitance of the dielectric cell and hence the dielectric constant. The circuit details are shown below:

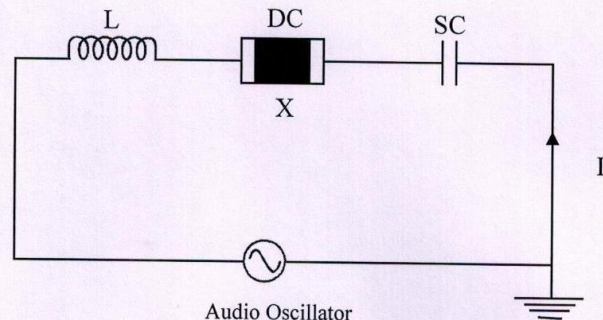


Figure 3

- DC : Dielectric cell
- SC : Standard capacitor
- L : Inductance
- X : Ferroelectric sample

The dielectric cell DC is placed in a tubular furnace which is fed by a variable ac power supply. By changing the voltage applied to the furnace, the temperature of the furnace can be varied. The temperature of the furnace can be measured by inserting a thermocouple in a hole (provided on one of the Teflon discs), so that it touches one of the capacitor (metal) plates.

The audio oscillator is incorporated inside the instrument. If  $C_{SC}$  and  $C_{DC}$  represents the capacitances of the standard capacitor and dielectric cell respectively and if  $V_{C1}$  and  $V_C$  are the voltages across SC and DC then.

$$\frac{V_{SC}}{I} = \frac{1}{\omega C_{SC}} \quad \dots\dots (1)$$

$$\Rightarrow I = \omega \cdot V_{SC} C_{SC} \quad \dots\dots (2)$$

The same current I passes through the dielectric cell.

$$\frac{V_{DC}}{I} = \frac{1}{\omega C_{DC}} \quad \dots\dots (3)$$

$$\Rightarrow C_{DC} = \frac{I}{\omega V_{DC}} = \frac{\omega C_{SC} V_{SC}}{\omega V_{DC}} = \frac{C_{SC} V_{SC}}{V_{DC}} \quad \dots\dots (4)$$

By measuring  $V_{SC}$  &  $V_{DC}$  and using the value of  $C_{SC}$  we can determine the capacitance of the dielectric cell containing the sample.

If  $C_0$  represents the capacitance of the dielectric cell without the crystal and the plates separated by air gap whose thickness is the same as the thickness of the crystal then  $C_0$  is given by

$$C_0 = \frac{\epsilon_0 A}{d} = \frac{r^2}{36d} \text{ nf} \quad \dots\dots (5)$$

where  $r$  represents the radius of the crystal and  $d$  represents its thickness

The dielectric constant of the crystal at any given temp. is given by

$$\epsilon_r = \frac{C}{C_0} \quad \dots\dots (6)$$

### CALIBRATION

- 1) Connect C.R.O. to the terminals provided on the front panel.
- 2) Switch ON the unit and put the voltage toggle switch towards DC. Adjust CAL. such that sinusoidal waveform appears on C.R.O. and  $V_{DC}$  voltage reads 3.5V approx.
- 3) Switch OFF the unit and disconnect C.R.O. from the main circuit.

### PROCEDURE

- 1) Connect C.R.O. to the terminals provided on the front panel. If no sinusoidal waveform appears on C.R.O. then follow calibration procedure first.
- 2) Assemble the dielectric capacitor as shown in figure (3) and connect it to the main unit. (For convenience we had send the assembled dielectric cell.)
- 3) Connect hot air oven to the mains.
- 4) Place the dielectric cell DC in hot air oven and place the lid on the top. Insert the thermocouple to the hole provided on top Teflon disc of DC via hole provided on the insulating disc. Make sure that thermocouple touches the top metal disc.
- 5) Switch ON the unit.

- 6) Select SC1 among standard capacitors.
- 7) Measure the voltage (using digital voltmeter provided on front panel) across the dielectric cell DC, say  $V_{DC}$ , by throwing switch  $S_1$  towards DC and measure voltage across standard capacitor SC, say  $V_{SC}$ , throwing switch  $S_1$  towards SC, while heater is switched off (i.e. at room temperature).

$$V_T = V_{SC} + V_{DC}$$

- 8) Determine the dielectric constant of the crystal using the relation

$$\epsilon_r = \frac{C}{C_0} = \frac{C_{SC} V_{SC}}{V_{DC} C_0} \quad \dots\dots (7)$$

where  $C_0$  is calculated using relation (5)

- 9) Switch ON the oven and set the desired temperature (Follow instructions to set the temperature of the oven). Measure voltages  $V_{DC}$  at different temperatures at  $10^\circ\text{C}$  interval in the range RT- $90^\circ\text{C}$ .  $V_{SC}$  may be calculated as

$$V_{SC} = V_T - V_{DC}$$

**NOTE: Readings should be taken in ascending order only.**

- 10) Measure  $V_{DC}$  at  $5^\circ\text{C}$  interval upto  $110^\circ\text{C}$  and at intervals of  $1^\circ\text{C} - 2^\circ\text{C}$  until you reach the maximum value of the dielectric constant ( or C ). Thereafter take few points.

**NOTE: Complete experiment may be carried out using SC<sub>1</sub> only. However, you may choose standard Capacitor SC1 for temperature upto  $90^\circ\text{C}$  and SC2 for temperature range  $90^\circ\text{C}$  to  $110^\circ\text{C}$  and SC3 for  $110^\circ\text{C}$  onwards.**

**IMPORTANT : DO NOT INCREASE THE TEMPERATURE OF OVEN BEYOND  $150^\circ\text{C}$ .**

- 11) Make the observation table as shown below:

TEMPERATURE ( $^\circ\text{C}$ )	SC1		SC2		SC3		CALCULATED CAPACITANCE	$\epsilon_r$
	$V_{DC}$	$V_{SC}$	$V_{DC}$	$V_{SC}$	$V_{DC}$	$V_{SC}$		

- 12) Calculate the dielectric constant ( as explained in step 8 ).
- 13) Draw a graph of  $\epsilon_r$  vs. T. At the transition the dielectric constant sharply rises and falls suddenly after the transition temperature and then decreases slowly beyond the transition temperature.

Fig. 5 shows the variations of dielectric constant of BaTiO<sub>3</sub> ceramic as a function of temperature (After W. B. Westphal, Laboratory for Insulation Research, M.I.T.). An examination of Figure 5 shows that it is difficult to make measurements at the Curie temperature due to sharp variation. Extension of the curves below and above the transition temperatures allows one to estimate the Curie temperature.

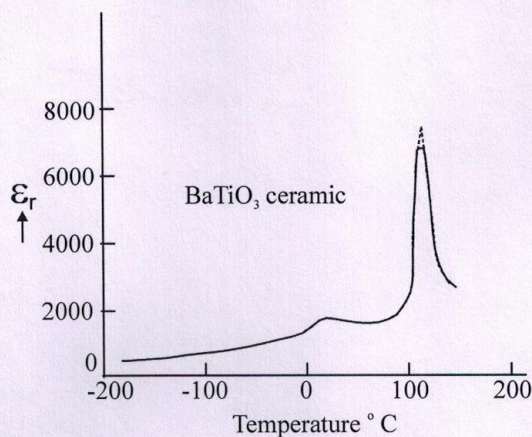


Figure 5

- 14) Determine the transition temperature ( Curie Temperature ) from the graph.

**NOTE: As the measurements are repeated the nature of the curve remains same but it might not be possible to get the same values.**

**Component Values (S.No. 1718327)**

**L = 25 mH**

**SC<sub>1</sub> = 20nf**

**SC<sub>2</sub> = 30 nf**

**SC<sub>3</sub> = 38 nf**

**Diameter of barium titanate disc = 21mm.(Make changes in calculation accordingly.)**

## INSTRUCTIONS TO SET THE DESIRED TEMPERATURE OF OVEN

(RT – 150 °C)

**Note:** Upper display (in red) shows current temperature reading and lower display (in green) shows set temperature.

1. Press up key (left most key on the controller cum indicator panel) or down key (middle key) to set the desired temperature.
2. Press enter (right most key) and hold for 1-2 sec.

**Note :** If after setting of desired temperature, enter key is not held for some time, it will go back to previous set value.

**:** If thermocouple is not connected to the Unit, upper display will show "open".

**IMPORTANT :** DO NOT CHANGE THE SETTING PARAMETERS OF CONTROLLER CUM INDICATOR.

### PARTS LIST

- |    |  |                          |
|----|--|--------------------------|
| 1. | MAIN UNIT  | <input type="checkbox"/> |
| 2. | ASSEMBLED DIELECTRIC CELL WITH TEFLON HOLDER           | <input type="checkbox"/> |
| 3. | PID CONTROLLED OVEN WITH DIGITAL TEMP. INDICATOR & LID | <input type="checkbox"/> |
| 4. | THERMOCOUPLE   | <input type="checkbox"/> |
| 5. | PATCH CORDS (2 nos)                                    | <input type="checkbox"/> |
| 6. | SPARE CRYSTAL  | <input type="checkbox"/> |
| 7. | INSTRUCTION MANUAL                                     | <input type="checkbox"/> |

Temp	Vsc	Vdc	SC(nf)	Capacitance C(nf)	Dielectric Constant K
28	0.74	2.73	11	2.98	1237
75	0.74	2.73	11	2.98	1237
85	0.75	2.72	11	3.03	1258
90	0.76	2.71	11	3.08	1279
95	0.78	2.69	11	3.19	1323
100	0.81	2.66	11	3.35	1389
105	0.86	2.61	11	3.62	1503
110	0.93	2.54	11	4.03	1670
115	1.05	2.42	11	4.77	1979
118	1.2	2.27	11	5.81	2412
119	1.29	2.18	11	6.51	2699
120	1.45	2.02	11	7.90	3275
121	1.94	1.53	11	13.95	5784
121.5	2.21	1.26	11	19.29	8001
<b>122</b>	<b>2.28</b>	<b>1.19</b>	<b>11</b>	<b>21.08</b>	<b>8740</b>
123	2.26	1.21	11	20.55	8521
124	2.21	1.26	11	19.29	8001
125	2.15	1.32	11	17.92	7430
127	2.06	1.41	11	16.07	6665

thickness of sample= 1.8 mm  
 radius of sample= 12.5 mm  
 Co= 0.002411 nf

