INDIAN INSTITUTE OF TECHNOLOGY, KANPUR

LABORATORY REPORT SHEET

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Section :
Date of Experiment : 22.10.24
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Experiments : Phase Transition in Barium Titanate

Subject : PHY461
Roll No : 210386
Instructor : Prof. Jayita Nayak
Remarks by the Instructor :

Phase Transition in Barium Titanate ($BaTiO_3$)

Aim : 1) To study the temperature dependence of a ceramic disc capacitor.

2) To study the temperature dependence of dielectric constant at 100 Hz and to determine phase transition of $BaTiO_3$.

Apparatus : LCR Bridge, Furnace, Sample, thermocouple and multimeter.

Theory : Let us take a capacitor of any arbitrary shape and dimensions with vacuum in the space between the electrodes (vacuum capacitor) and denotes its capacitance by C_0. If now inter-electrode space is filled by a material having permittivity ε, the new capacitance C is given by $C = \varepsilon C_0$.

In the case of a parallel plate capacitor eq.(1) becomes

$C = \frac{\varepsilon \varepsilon_0 A}{d}$, $\varepsilon_0 = 8.854 \times 10^{-12}$ F/m is the permittivity of free space.

A is the area of plates, d is the separation between the plates.

ε is the dimensionless parameter which characterizes the dielectric and is called the relative permittivity or dielectric constant.

Dielectrics are sub divided into two classes

a) Polar dielectrics → composed of molecules having permanent dipole moments.

b) Non-polar dielectrics → do not have molecules containing permanent dipole moments.

A further classification is done as linear and non-linear dielectrics. Linear dielectrics are characterized by the fact that their polarization P and displacement D are directly proportional to the intensity of electric field E.

$P = k_e \varepsilon_0 E$

$D = \varepsilon \varepsilon_0 E$, where $k_e \varepsilon_0$ is absolute dielectric susceptibility.

$\varepsilon = 1 + k_e$

For the case of non-linear dielectrics, there is no proportionality between P. & D. Ferroelectrics (FE) are most typical non linear dielectrics. The most essential features are:

1) a hysterisis D-E loop akin to B-H loop of ferromagnetic materials
2) Usually a high value of permittivity.
3) Pronounced dependence of dielectric parameters on temperature.
4) Presence of a spontaneous polarization without an external electric field.

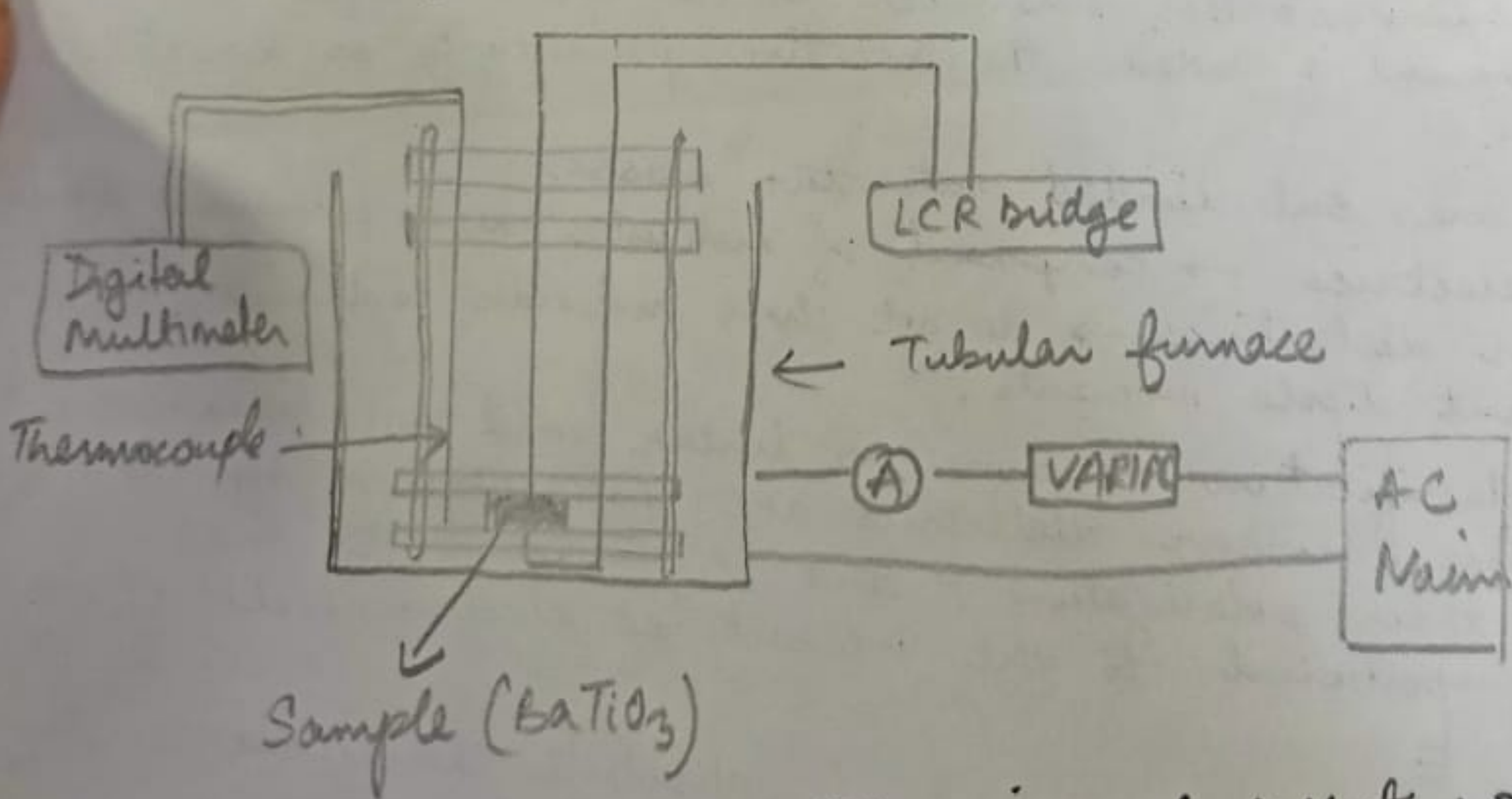
Barium Titanate ($BaTiO_3$) is one of the important FE materials and it displays FE properties also in poly crystalline formations obtained as products of required shape and dimensions by ceramic-process methods. The templelature dependence of permittivity and some other physical properties of FE are characterized by the presence of transition points called "Curie points" at which the magnitude of permittivity is maximum, and substance acquires or loses FE properties when temperature passes through the Curie point. The phase above the curie point is called "Paraelectric (PE) phase" and the phase below it is called the FE phase. Therefore PE ⇔ FE phase transition (PT) occurs at the Curie point. The permittivity near the PT and above the curie point is governed by Curie-Weiss Law:

$$\varepsilon = \frac{C}{(T-T_0)}$$, where C is the Curie-Weiss constant and T_0 is the Curie-Weiss temperature close to the Curie point.

The capacitance can be measured directly with the help of LCR bridge. The total current I through the capacitor is resolved into the two components active current I_a and reactive current I_r. I_a is in phase with V and I_r leads by $\pi/2$. The angle δ is called the dielectric loss angle.

$$Q = \frac{1}{\tan\delta}$$ (Quality factor of the dielectric)

Systematic experimental setup:



Dimensions of Pellet : $2r = (10.7 \pm 0.4)$ mm

$d = 3.1 \pm 0.1$ mm

For $BaTiO_3$

Frequency = 100 Hz

V_{offset} = 1.1220 - 0.00 = 1.1220

Room temperature = 28°C

Temperature	Corresponding Voltage ($V_{Tc} - V_{offset}$) (mV)	C (nF)		tan δ	
		Heat	cool	Heat	cool
28	0	1.360	–	0.061	–
35	0.29	1.378	–	0.095	
40	0.49	1.382	0.0658	0.096	1.848
45	0.70	1.388	0.0617	0.102	1.629
50	0.90	1.394	0.0582	0.102	1.750
55	1.11	1.409	0.0612	0.105	2.216
60	1.31	1.418	0.0625	0.107	2.730
65	1.52	1.438	0.086	0.111	2.778
70	1.73	1.460	0.109	0.112	2.709
75	1.94	1.489	0.145	0.118	2.550
80	2.14	0.0650	0.202	2.515	2.233
85	2.35	0.0824	0.297	2.806	1.948
90	2.56	0.1237	0.399	2.711	1.670
95	2.77	0.1979	1.544	2.357	0.892
100	2.97	0.3059	1.229	1.961	0.691
105	3.18	0.4928	1.433	1.552	0.590
110	3.39	0.7269	1.634	1.245	0.527
115	3.59	0.9934	1.926	1.009	0.435
120	3.80	1.334	2.251	0.851	0.407
125	4.00	1.690	2.756	0.774	0.392
130	4.21	2.239	3.314	0.683	0.340
135	4.41	2.704	3.131	0.517	0.265
140	4.61	2.706	2.890	0.387	0.228
145	4.81	2.601	2.694	0.303	0.206
150	5.02	2.457	2.534	0.247	0.190
155	5.22	2.322	2.370	0.211	0.177
160	5.42	2.193	2.178	0.187	0.165

(signature) $\times 10^{-}$

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Results and Analysis

* For the case of the commercial capacitor, we can see that the capacitance decreases with temperature. We have fitted a curve with the data observed and attached it along with the report.

* For $BaTiO_3$, if we consider the heating part, phase transition happens at $T \simeq 80°C$. While for the cooling part phase transition happens at $T = 90°C$.

Error Analysis

We know that capacitance $C = \frac{A\varepsilon}{d} = \frac{2\pi r^2}{d}\varepsilon$

Given, $2r = (10.7 \pm 0.4)$ mm , $d = 3.1 \pm 0.1$ mm

At room temperature, for $BaTiO_3$, $C = 1.360$ nF

$$\Rightarrow \varepsilon = \frac{1.360 \times 10^{-9} \times 3.1 \times 10^{-3}}{2 \times \pi \times (10.7)^2 \times 10^{-6}} = 5.86 \times 10^{-9} \text{ F/m}$$

$$\varepsilon_r = \frac{\varepsilon_0}{\varepsilon} = \frac{8.85 \times 10^{-12}}{5.86 \times 10^{-9}} = 1.51 \times 10^{-3}$$

$$\frac{\Delta\varepsilon}{\varepsilon} = 2\frac{\Delta r}{r} + \frac{\Delta d}{d}$$

$$\Rightarrow \Delta\varepsilon = \left(2 \times \frac{0.4}{10.7} + \frac{0.1}{3.1}\right) \times 5.86 \times 10^{-9} = 6.27 \times 10^{-10} \text{ F/m}$$

So $\varepsilon = (5.86 \pm 0.63) \times 10^{-9}$ F/m

Observation Table

For frequency = 100 Hz . Room temperature = 29°c , V = 0 v

I = 1.33 mA V_{offset} = 1.1626 − 0 = 1.1626

Temperature (°c)	Corresponding Thermo-couple Voltage ($V - V_{offset}$)	C (nF) Heat	C (nF) cool	tan δ Heat	tan δ cool
29°	0	6.094		0.013	
35	0.24	6.143		0.013	
40	0.45	6.246		0.014	
45	0.65	6.131		0.013	
50	0.86	5.895		0.012	
55	1.07	5.597		0.012	
60	1.27	5.298		0.011	
65	1.48	4.948		0.011	
70	1.69	4.589		0.011	
75	1.90	4.219		0.010	
80	2.10	3.883		0.010	
85	2.31	3.556		0.010	
90	2.52	3.257		0.011	
95	2.73	2.951		0.012	
100	2.93	2.679		0.013	
105	3.14	2.486		0.015	
110	3.35	2.270		0.019	
115	3.55	2.080		0.024	
120	3.76	1.920		0.030	
125	3.96	1.785		0.038	
130	4.17	1.650		0.050	
135	4.37	1.551		0.063	
140	4.57	1.461		0.079	
145	4.77	1.429	1.	0.086	
150	4.98	1.383	[illegible]	0.099	

* We could not get the data for cooling as the heating part took a lot of time and not enough time was left to take the cooling data on the same day.

Solutions to Lab Manual Questions

1. Dielectrics → They are insulating materials that do not conduct electricity but can be polarized in an electric field. They store electrical energy in the form of electric dipoles. Example → Glass.

Ferroelectrics → They are materials that exhibit spontaneous polarizations. They have permanent electric dipole moment even in the absence of an electric field. Example → $BaTiO_3$

Paraelectrics → They are materials that exhibit a weak polarization that can be induced by an external electric field but do not have spontaneous polarization.
Ex. $SrTiO_3$ (Strontium Titanate)

2. The DC value of dielectric constant is measured under a steady electric field. It's polarization in this case is mainly due to the displacement of charge carriers and the alignment of dipoles.

The AC value of dielectric constant is measured under an alternating electric field. As the frequency increases, the dielectric material may not have enough time to respond to the rapid changes in the electric field. affecting the overall dielectric response.

As frequency increases, the dielectric constant typically decreases leading to decrease in capacitance.

3. 1st order phase transition → Characterized by a discontinuity in the first-derivative of the free energy with respect to temperature and pressure. Eg. Melting of ice

II° order phase transition → No discontinuity in first derivative. However higher derivatives show discontinuity.

$BaTiO_3$ is a first order transition

4. Polar Dielectrics → Have permanent dipoles and exhibit spontaneous polarization. Ex → $BaTiO_3$

Non Polar Dielectrics → Lack Permanent dipoles and become polarized only in an external field.

* Polar dielectrics can maintain polarization without an external field while non-polar dielectrics require an electric field to exhibit polarization.

5. In this Equation

ε : Real part of the permittivity representing stored energy.

ε'' : imaginary part of the permittivity representing energy lost (dielectric loss)

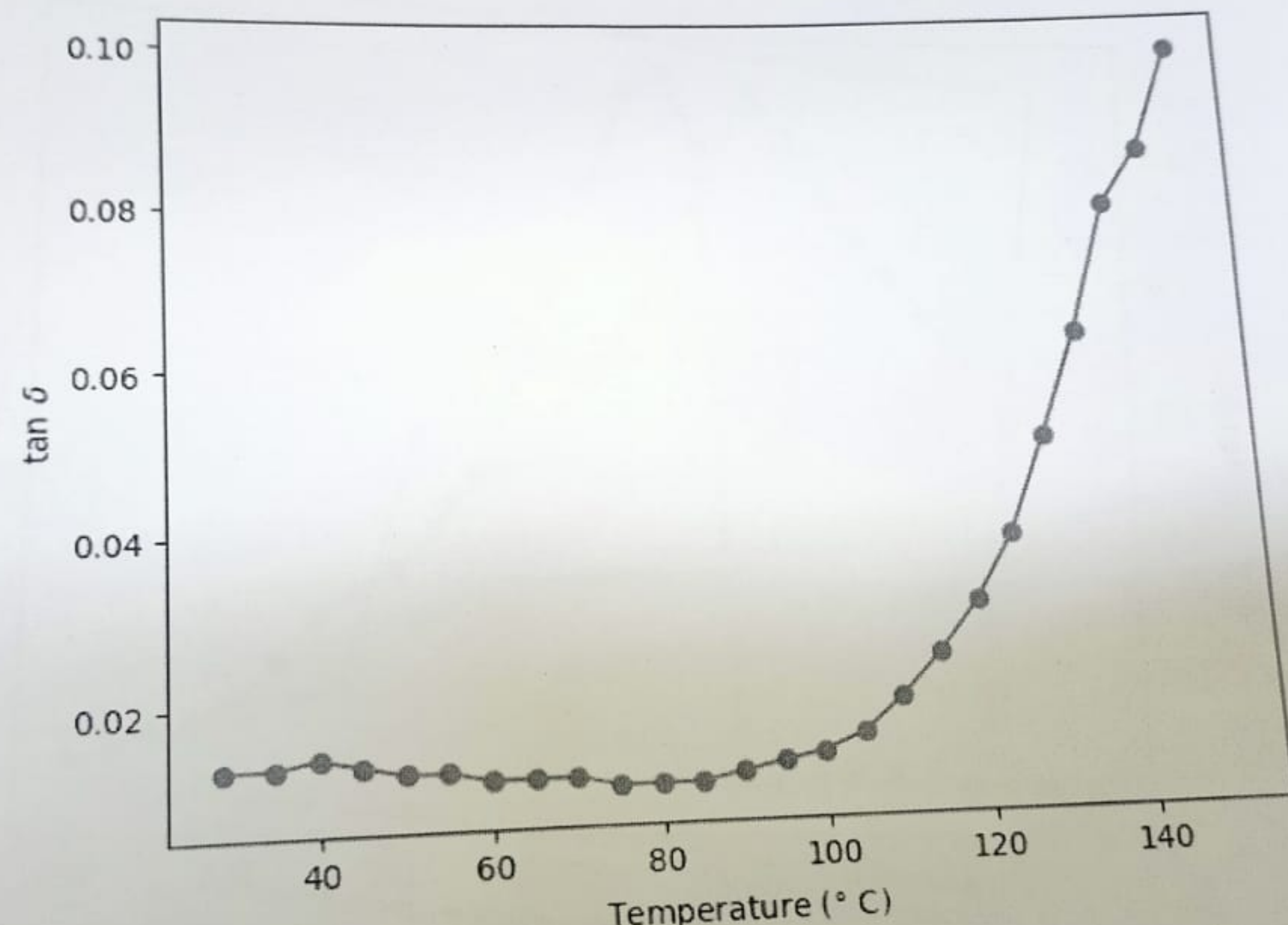
At low frequency, polymer can exhibit high dielectric constant due to dipolar polarization. At high frequency two dipoles may not have enough time to align with field leading to decrease in ε', and an increase in ε''.

Curie's constant $= \varepsilon (T - T_0)$

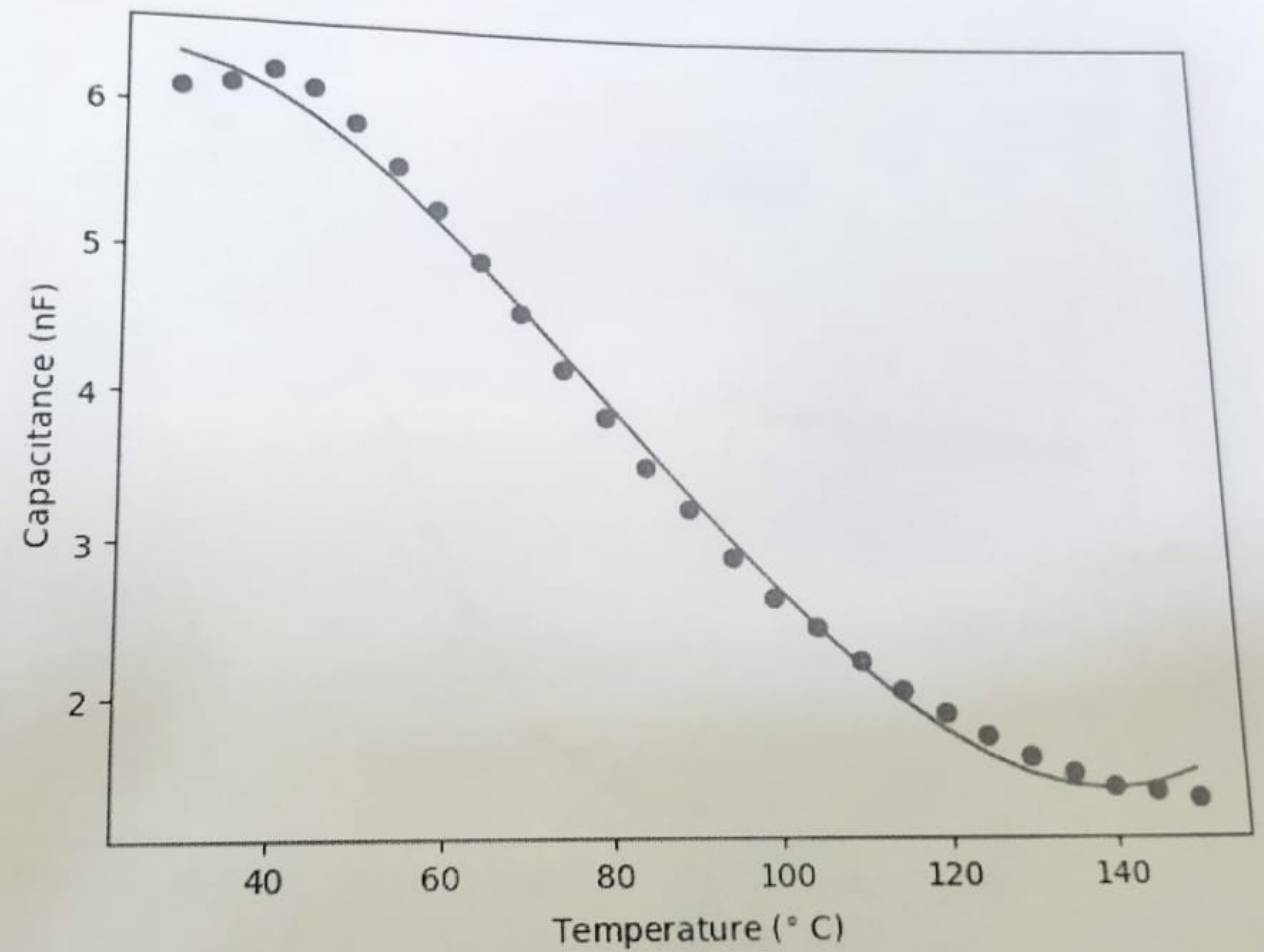
$T_0 = 80°c$ (for heating part)

$\Rightarrow C = 5.86 \times 10^{-9} (T - 80)$

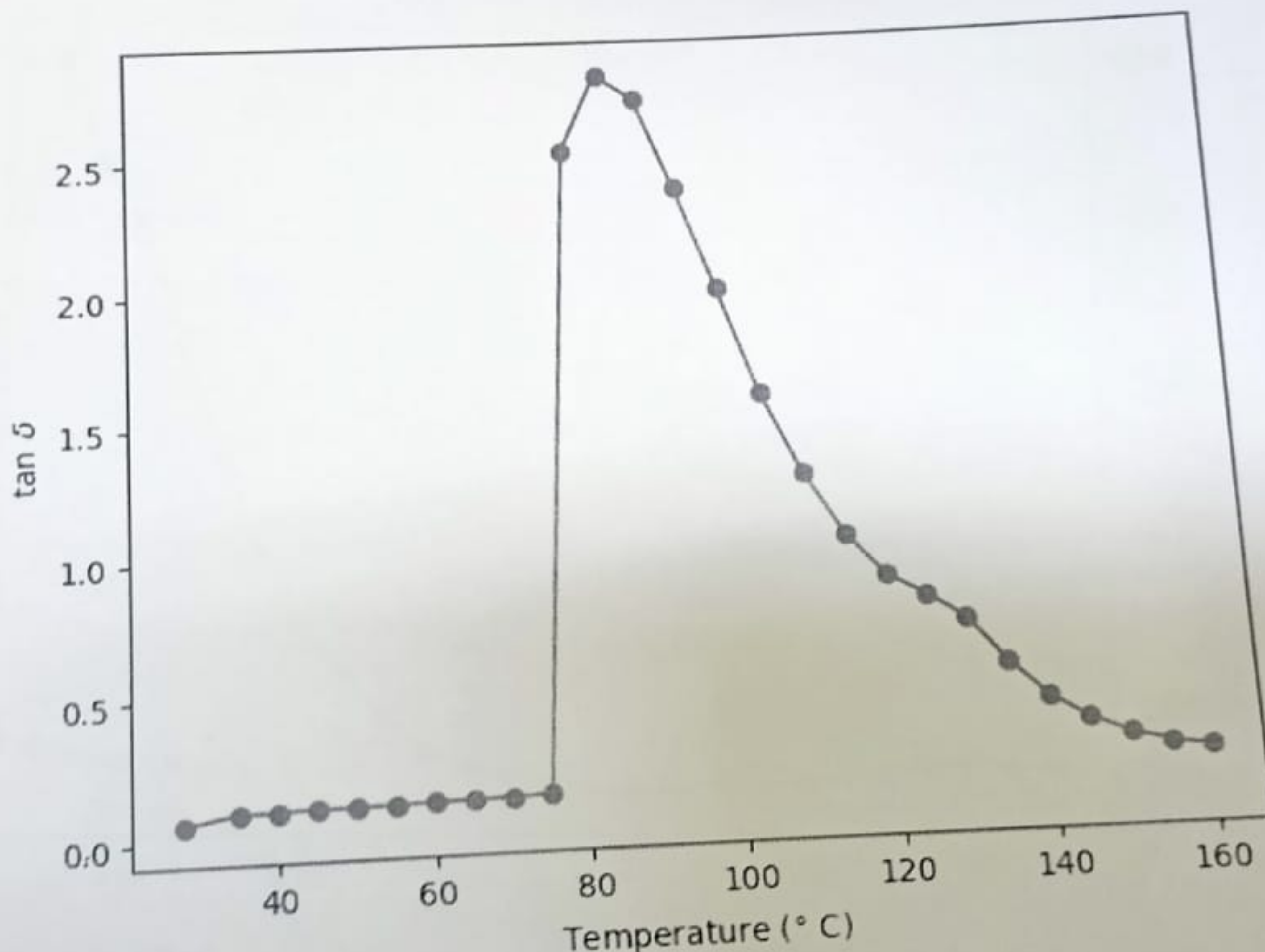
For commercial capacitor
Freq = 100 Hz



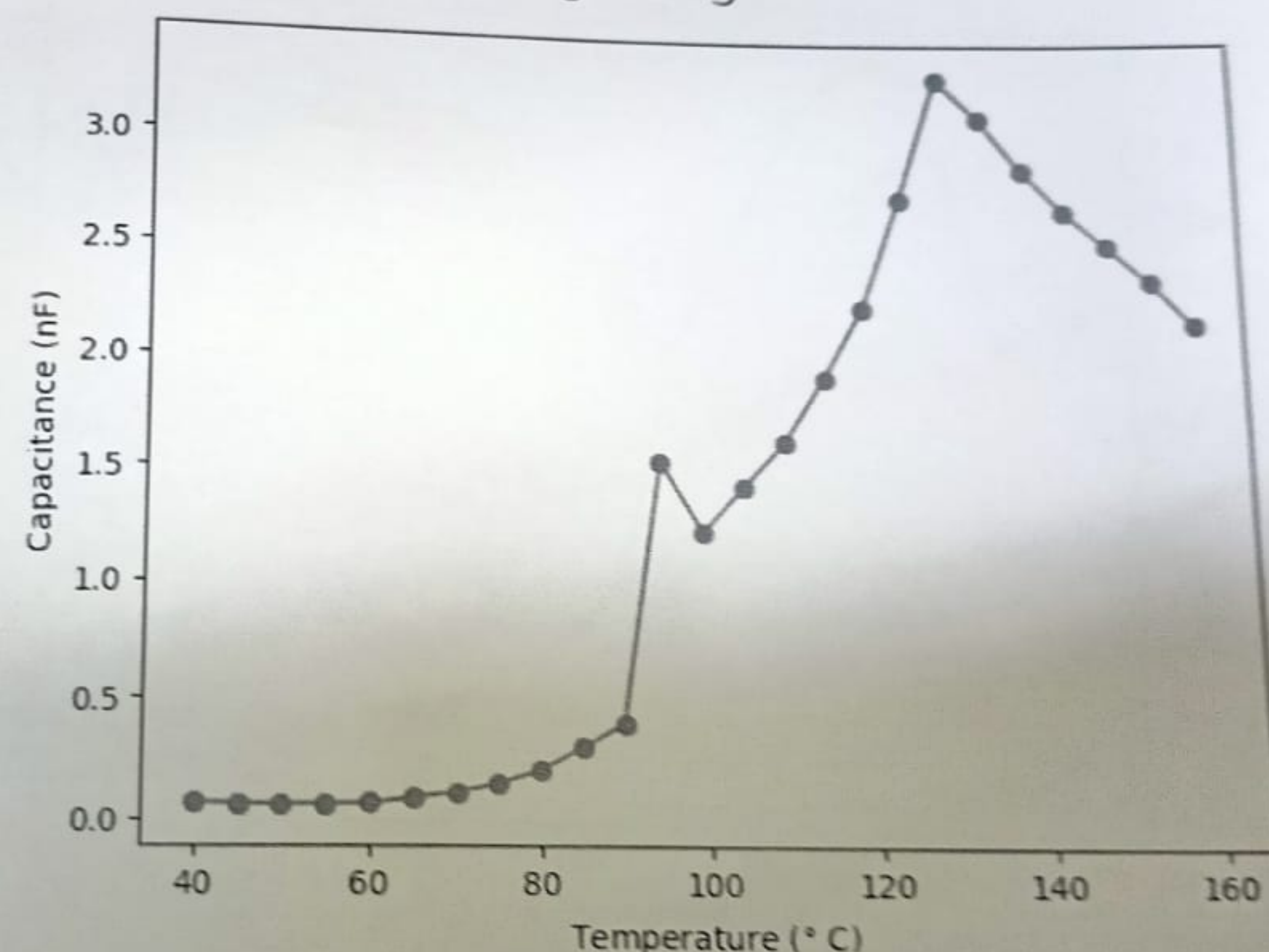
For commercial capacitor
Freq = 100 Hz



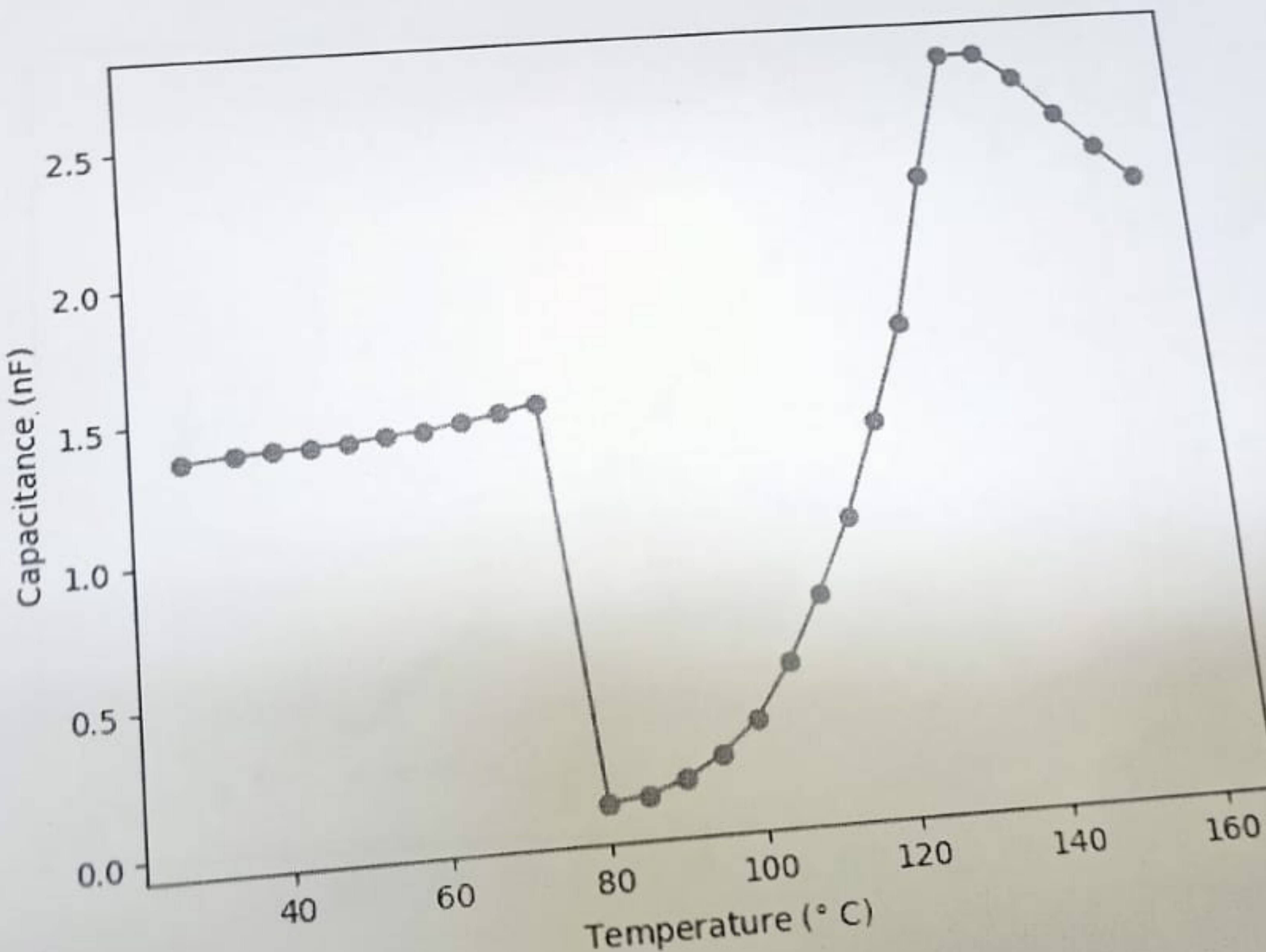
For $BaTiO_3$
Freq = 100 Hz
During Heating



For $BaTiO_3$
Freq = 100 Hz
During cooling



For $BaTiO_3$
Freq = 100 Hz
During Heating



For $BaTiO_3$. For freq = 100 Hz
During cooling