Investigation of Dielectric Properties of Liquid Crystals near Phase Transitions

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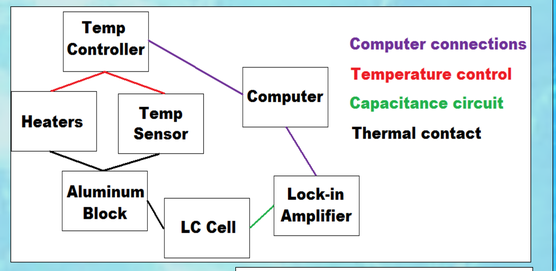
Abstract

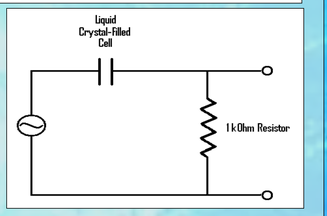
Precise capacitance measurement has been performed near the phase transitions of scientifically important liquid crystals such as 8-CB. The details of the measurements to get high precision data on dielectric constant and its temperature dependence will be presented.

The results show significant changes of the dielectric properties of the liquid crystal near the smectic-to-nematic and nematic-to-liquid phase transitions attributed to structural changes of the relevant phases. In order to measure the details of the functional dependence near the phase transition, the temperature was varied with milliKelvin precision. The data was obtained using a self-assembled RC circuit with phase sensitive lock-in amplifier detection. Calibration of the device was made by measuring known standard capacitances. In order to get high accuracy the measurement was completely computer controlled. The Method applied here will contribute to the better understanding of thermodynamic behavior of liquid crystals and can be routinely used to characterize novel materials showing phase transitions.

Setup



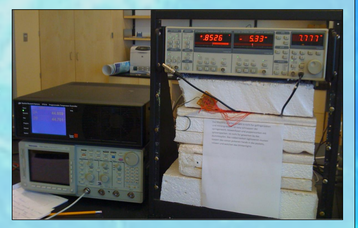
Temperature controller: Regulates the power to the heaters based on temperature with a PID algorithm and milliKelvin precision



Heaters: Eight heaters are strategically placed on the box to evenly distribute heat throughout the block

Temperature sensors: 100 Ohm RTD platinum resistance thermometers, one for temperature regulation, one for measurement

Aluminum block: Used as a heat reservoir for temperature adjustment and stability



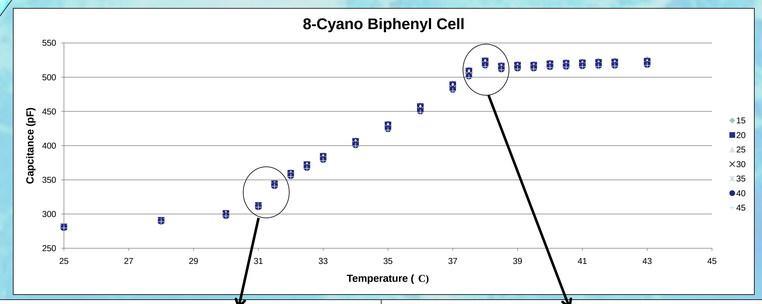
Lock-in amplifier: Displays the phase angle and potential used to determine the capacitance of the cell

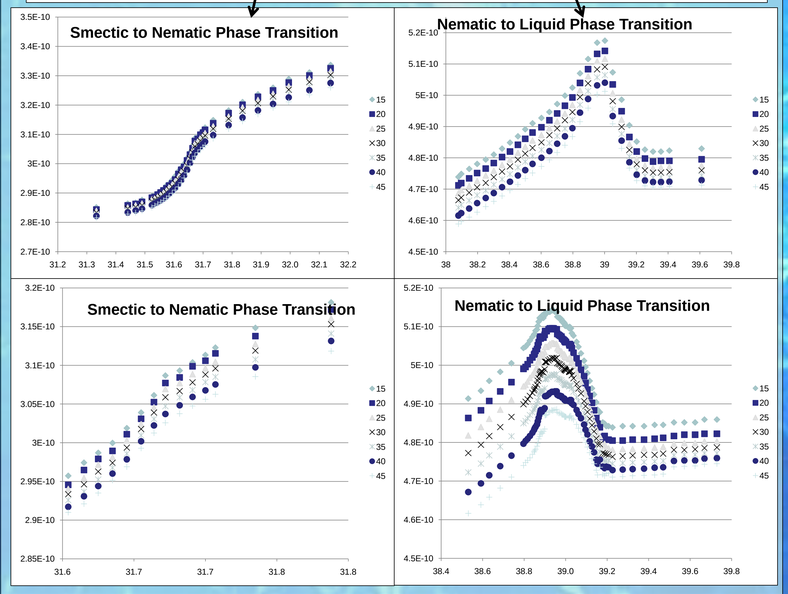
Liquid crystal cell: Commercially available cell filled with liquid crystal.

Computer: Used for control and data acquisition.

Experiment

The capacitance of the liquid crystal cell was measured using the Lock-in Amplifier by determining the frequency response of an RC circuit using the liquid crystal cell as the capacitor. The frequency was varied from 15 to 45 kHz in 5 kHz intervals in order to determine the capacitance across multiple input frequencies. The temperature was varied from 25ºC to 50ºC, concentrating data points and multiple runs around phase transitions.





Liquid Crystals

Liquid Crystals exhibit phases between solid and liquid where they flow like liquids but maintain a crystalline structure.

Three major categories of liquid crystals:

- **Thermotropic** liquid crystals exhibit different phases due to temperature variations.
- **Lyotropic** liquid crystals are formed due to their concentration in a solvent.
- **Polymeric** liquid crystals are simply the polymer versions of the monomers above.

Basic types of liquid crystals:

- Benzene derivatives
- Heterocyclics
- Organometallics
- Sterols
- Organic salts
- Fatty acids

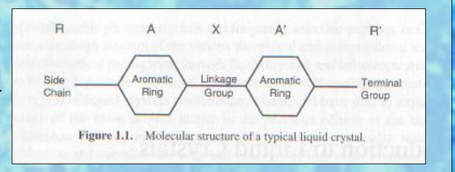


Figure 1.1. Molecular structure of a typical liquid crystal.

Important phases of thermotropic liquid crystals:

- **Smectic** – liquid crystal molecules possess positional order, and the liquid crystal as a whole possesses a net dipole moment
- **Nematic** – liquid crystal molecules are centrosymmetric but possess no net dipole moment
- **Cholesteric** – chiral nematic phase

Smectic Phase

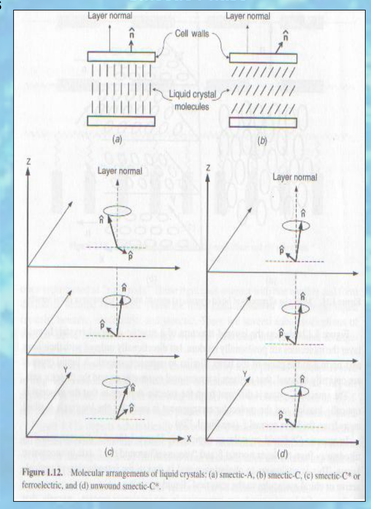
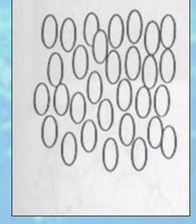
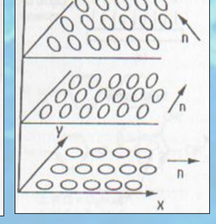


Figure 1.12. Molecular arrangements of liquid crystals: (a) smectic-A, (b) smectic-C, (c) smectic-C* or ferroelectric, and (d) unwound smectic-C*.

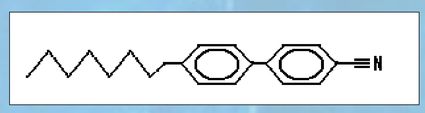
Nematic Phase



Cholesteric Phase



8-Cyanobiphenyl



Major Equipment

Model SR-830 Lock-In Amplifier

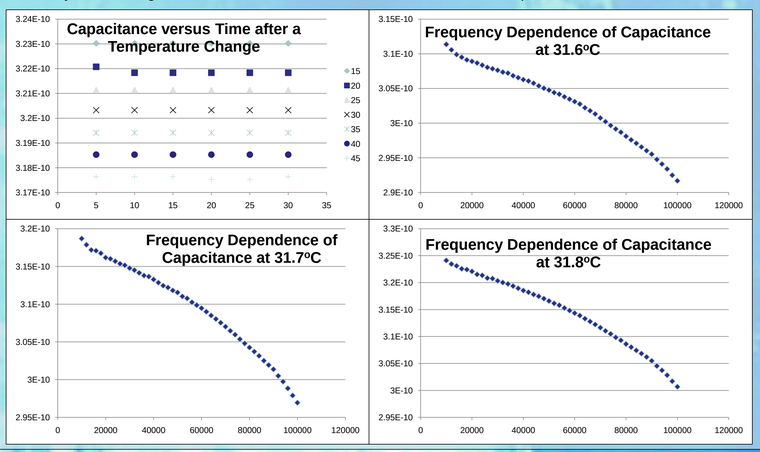
For the purposes of this experiment, the Lock-In Amplifier is used to measure the capacitance of liquid crystal cells. This is done by measuring the amplitude (Channel 1) and the phase shift (Channel 2) of a signal passed through the liquid crystal cell referenced against its own output signal. The Lock-In Amplifier allows for measurements at multiple frequencies.

Model PTC10 Programmable Temp. Controller

For the temperature control and resolution necessary for this experiment, a milliKelvin temperature controller was used. This allowed the liquid crystal to be brought very close to the phase transition (within < 5 mK)

Method Tested

In order to test and verify the reliability and stability of the set-up, the frequency dependence was measured at several fixed temperatures, and the capacitance was determined after a major temperature change over a period of 30 minutes. This was to ensure that the liquid crystal was responding properly to the temperature changes and to verify that the data was being collected at the proper frequencies. Of course, this was in addition to the system being checked and verified with several fixed value capacitors.



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Future Goals

- Dielectric constants of different liquid crystals
- Dielectric relaxaion of liquid crystal
- Optical properties of liquid crystals
- Magnetic susceptibility of liquid crystals