Summer Project Report (Summer 2023)

Learning Techniques and Methods for Experimental Soft Matter Physics

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Abstract

This report details some of the techniques and methods needed to get started with Liquid Crystal research. The important measurement tool used here is the Lock In Amplifier. It is an important skill to know how to work with a LIA. The LIA has been used to measure the resistance of a piece or copper wire which would not be possible using ordinary multimeters. Then, measurements with a LC cell are carried out. The effects of applying an external electric field are observed. This serves as a starting point to learn the basic techniques required in order to build on this and carry out more complex experiments.

1 Using the lock in amplifier (LIA) to measure very small resistance

For this section, Basic Lock-in Amplifier Experiment for the Undergraduate Laboratory Libbrecht et al. (2003) was used as the primary source.

Working of an LIA

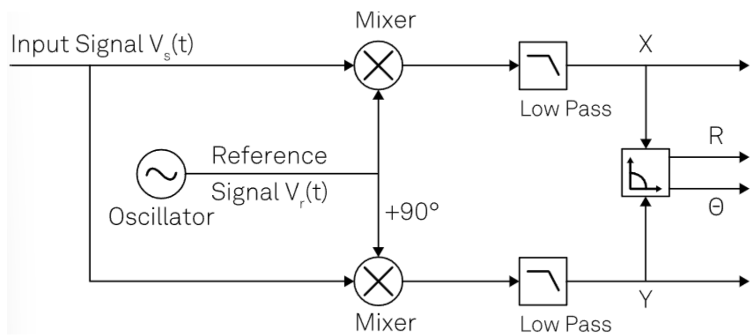

Figure 1: Schematic Diagram for a simple LIA. source: Zurich Instruments, n.d., `https://www.zhinst.com/others/en/resources/principles-of-lock-in-detection`

Lock in amplifiers are used to make high precision measurements. Where a small signal is to be detected in a lot of noise. For an electronic output signal consider the output signal to be as follows:

$$V_{\text{signal}}(t) = V_o + V_{\text{noise}}(t)$$

Here we assume the response of the system, the output signal we wish to measure, to be constant. We thus have to deal with the noise. How we do so depends on the type of noise at hand. In case of Gaussian noise (pure white noise), the value of noise at some time $V_{\text{noise}}(t)$ and that at some other time $V_{\text{noise}}(t')$ are completely uncorrelated if the interval between them is greater than some characteristic correlation time τ. To deal with this we can just average our output signal as Gaussian noise has en expectation value zero. Thus giving,

$$\langle V_{\text{signal}}(t)\rangle = \langle V_o\rangle + \langle V_{\text{noise}}(t)\rangle \implies V_o$$

But this is not a situation we will usually find ourselves in. We see that the apparatus used in the lab such as an amplifier have outputs which show more and more deviations with time. The frequency spectrum of such devices are seen to go as the inverse of the frequency. This is called $1/f$ noise. We can then modify the expression for the output as,

$$V_{\text{signal}}(t) = V_o + V_{\text{white noise}}(t) + V_{1/f\text{ noise}}(t)$$

Averaging over long time periods helps with taking care of the large frequencies but the low frequency noise persists. We use Lock-In Amplifiers in such cases to reduce noise and measure small signals which would ordinarily be drowned out in noise. We need to provide two signals to a LIA, the signal input and s reference frequency. This is the frequency at which the signal is modulated. This "locks" the frequency and phase. The references is often a square wave of several volt amplitude. This is converted to a sinusoidal wave and we get the output as,

$$V_{\text{out}} = \langle V_{\text{signal}}(t) \cos(\omega t + \phi) \rangle \tag{1}$$

Here, a dual-phase LIA has been used which gives the following outputs,

In phase output,

$$V_X = \langle V_{\text{signal}}(t) \cos(\omega t + \phi) \rangle$$

and quadrature output,

$$V_Y = \langle V_{\text{signal}}(t) \cos(\omega t + \phi) \rangle$$

Measuring the Resistance of a Copper Wire

Here, the LIA has been used to measure a value of resistance far lower than what would be possible with a normal multimeter. A known current is passsed through the wore and the voltage across it is measured. The circuit used is shown in the diagram below

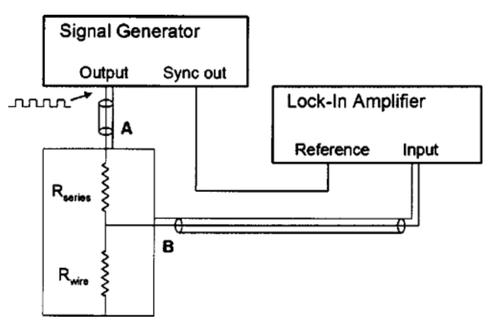

Figure 2: Circuit used measure the resistance of a copper wire. source: Libbrecht et al., 2003, `https://www.researchgate.net/publication/30770448-A-basic-lock-in-amplifier-experiment-for-the-undergraduate-laboratory`

The resistance of the wire is given as,

$$R_{\text{wire}} = \frac{V_B}{V_A} R_{\text{series}} \left(1 + \frac{R_{\text{wire}}}{R_{\text{series}}}\right) \tag{2}$$

As the value of R_{series} is 1 kΩ the term $R_{\text{wire}}/R_{\text{series}} << 1$ and thus can be neglected we have,

$$R_{\text{wire}} = \frac{V_B}{V_A} R_{\text{series}} \tag{3}$$

The copper wire used had a diameter of 0.55 millimeter and a section of length 39.7 centimeter was used. Using values of resistivity available on the internet, the expected value of the resistance was between 26.7 mΩ and 28.8 mΩ The value of voltage V_A was set to 1 volt. After doing so, the circuit as shown in the figure was assembled and the value V_B was measured for various frequencies of the input waveform. The following values of resistance were obtained.

Sr. no.	Frequency (kHz)	Value of resistance of wire (mΩ)
1	0.5	26.8
2	1	26.5
3	1.5	26.4
4	2	26.4
5	2.5	26.3
6	3	26.4
7	3.5	26.9
8	4	26.7
9	5	26.6

Thus the value of the resistance of the piece of copper wire was measured to be using a LIA to be,

$$R_{series} = 26.56 \text{ m}\Omega \tag{4}$$

2 Power dissipation across a liquid crystal cell

Electroconvection in Nematic Liquid Crystals

In nematic liquid crystals, electroconvection is observed in presence of an electrical potential gradient when the potential difference exceeds a certain value V_c. We use the compound

MBBA has a negative dielectric anisotropy,$\epsilon_a = \epsilon_{\parallel} - \epsilon_{\perp}$ and the director $\mathbf{n}$ is i the plane of the layer. On applying an external electric field we see an instability which leads to the distortion of the director and the appearance of fluid convection rolls (Kumar, 2010). We can see a regularly spaced pattern of lines under a polarising microscope. The mechanism behind the formation of these rolls was explained in one dimension by Helfrich (1969). Looking at the argument in the 1969 paper by Helfrich, Consider the following initial configuration:

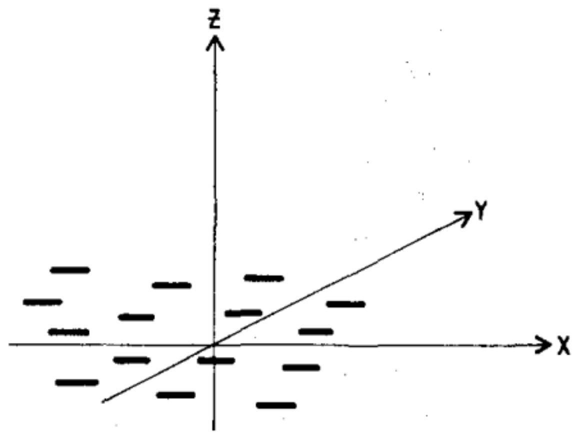

Figure 3: Initial configuration of LC. source: Helfrich, 1969, `https://pubs.aip.org/aip/jcp/article-abstract/51/9/4092/85337/Conduction-Induced-Alignment-of-Nematic-Liquid?redirectedFrom=fulltext`

let θ and ϕ be the angles of distortion in the y and z axis respectively. We can express these as $\theta(x)$, $\theta(y)$, $\theta(z)$, $\phi(x)$, $\phi(y)$, $\phi(z)$. Consider an applied electric field F_x if we consider the anisotropy in conductivity $\sigma_{\parallel} > \sigma_{\perp}$ and $\epsilon_{\parallel} > \epsilon_{\perp}$ we get the following expressions:

$$F_{\sigma,x} = -\left[\frac{(\sigma_{\parallel} - \sigma_{\perp})\cos\theta\sin\theta}{\sigma_{\parallel}\cos\theta^2 + \sigma_{\perp}\sin\theta^2}\right] F_z \tag{5}$$

$$F_{\epsilon,x} = -\left[\frac{(\epsilon_{\parallel} - \epsilon_{\perp})\cos\theta\sin\theta}{\epsilon_{\parallel}\cos\theta^2 + \epsilon_{\perp}\sin\theta^2}\right] F_z \tag{6}$$

The shear stress produced by the applied electric field is,

$$\pm\frac{(\epsilon_{\parallel}\cos\theta^2 + \epsilon_{\perp}\sin\theta^2)(F_{\sigma,x} - F_{\epsilon,x})}{4\pi} \tag{7}$$

Now, consider a single axis of variation which will allow us to look at all the distortions in which the deviation varies along a single direction. Consider the following unit vector:

$$\zeta = (\cos\alpha,\ \ \sin\alpha\cos\beta,\ \ \sin\alpha\sin\beta) \tag{8}$$

Then any infinitesimal distortions can be expanded as sinusoidal perturbations as (Helfrich, 1969),

$$(\theta,\ \phi) = (\theta_0,\ \phi_0) \cos q\zeta\mathbf{r} \tag{9}$$

Where, $q\zeta$ is the perturbation vector and $\mathbf{r} = (x,\ y,\ z)$.

The balancing act between an instability mechanism and a slower stabilising mechanism is key for pattern forming systems such as nematic liquid crystals (Dennin et al., 1995) We see the appearance of travelling rolls as shown in the diagram below:

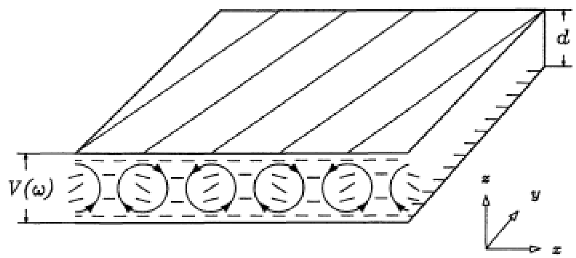

Figure 4: Diagram showing the apperance of travelling rolls in the LC cell. source: Bodenschatz et al., 1988, `https://www.semanticscholar.org/paper/On-electrically-driven-pattern-forming-in-planar-Bodenschatz-Zimmermann/2c60282cbc7de11ae26efc747c9d7c2e987aac92`

In the experiment we noted first passed a supply current of various frequency at a voltage amplitude for which the electroconvection rolls just start to appear. We then measure the distance between the subsequent rolls, the "wavelength", to see how it changes with the supply frequency we get the following graph:

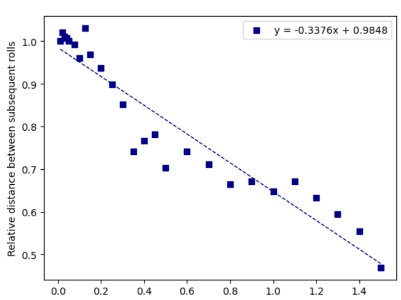

Figure 5: Frequency of supply vs the distance between rolls data set 1

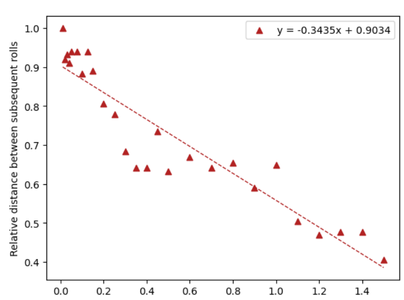

Figure 6: Frequency of supply vs the distance between rolls data set 2

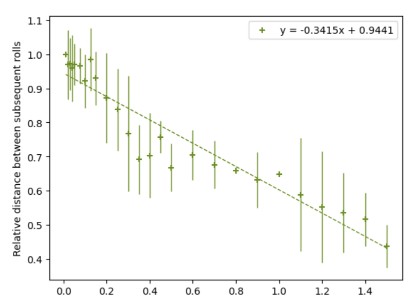

Figure 7: Frequency of supply vs the distance between rolls mean of the two sets

We get a linearly decreasing trend for two independent data-sets shown in the graph. The slopes for the two from the lines of best fit are -0.3376 and -0.3435 respectively.

Then we connected the liquid crystal cell in the same circuit that was used to measure the resistance of the wire in order to measure the power dissipation across the cell when a supply voltage at a fixed frequency is given. The voltage measurements were done using a LIA. Thus we got the two components of voltage, the real V_x and the imaginary V_y. The V_y component is of interest to us as it gives the power dissipated when the voltage supply is applied across a LC cell.The following graphs are obtained from the dissipation data collected:

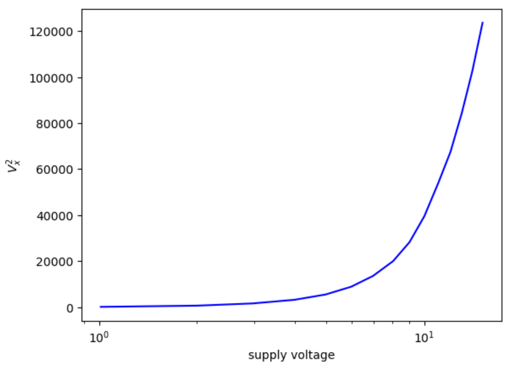

Figure 8: Power supply vs V_x

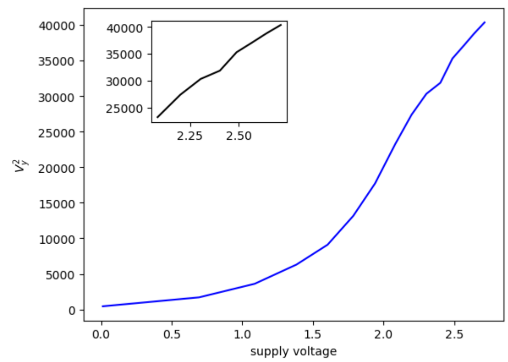

Figure 9: Power supply vs V_y (dissipative)

The component V_y of the voltage is the dissipative term which can be seen to increase with the supply voltage. The appearance of the kink is highlighted in the graph This trend and the apearance of the kink is in agreement with the results obtained by Toth-Katona and Gleeson (2004).

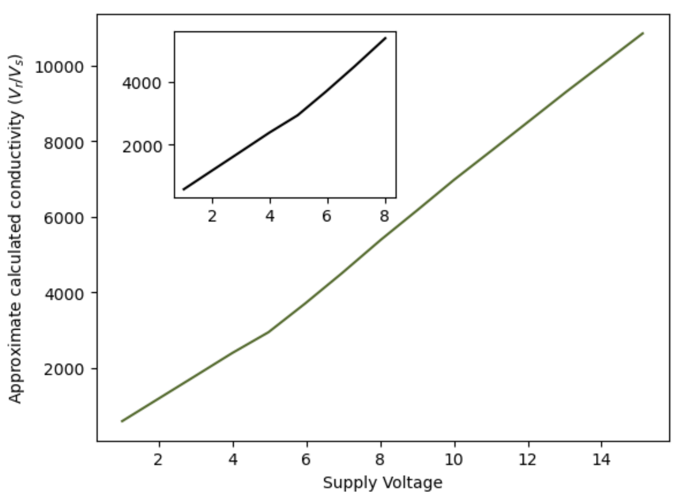

Figure 10: Power supply vs $V_R/V_{suppply}$

As a further check the dimensional equivalent of the conductivity of the cell V_R/V_{supply} is plotted and this trend also shows an increasing trend with the appearance of the kink which agrees with the results from Toth-Katona and Gleeson (2004).

Through these experiments the important techniques learnt were:

1. Learning to use the Lock In Amplifier in order to carry out high precision measurements
2. Making a liquid crystal cell of a desired thickness. Including the processes of making appropriate conducting regions, rubbing, connecting electrodes to apply electric field.
3. Observing the LC cell under a transmission microscope and capturing images and image series to analyse.
4. Image analysis using the ImageJ software.
5. Measuring the thickness of an LC cell using Diffraction and UV-Vis spectrometry.

Acknowledgement:

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References

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