expEYES and Lattice Dynamics

Saumya Prakash Sharma-1911151

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Part I
Experiments with expEYES:

1. To study electromagnetic induction
2. To study optoelectricity
3. To study IC-555 multivibrator

Introduction to expEYES & Abstract:

The ability to perform experiments with reasonable accuracy opens up the possibility of research oriented science education. Students can compare the experimental data with mathematical models and examine the fundamental laws governing various phenomena. Research scientists do the same with highly sophisticated equipment. The expEYES (expEriments for Young Engineers & Scientists) kit is designed to support a wide range of experiments, from school to post graduate level. It also acts as a test equipment for electronics engineers and hobbyists. The simple and open architecture of expEYES allows the users to develop new experiments, without getting into the details of electronics or computer programming.

1 EM induction experiment

1.1 OBJECTIVE:

Study of the voltage induced across a coil by a changing magnetic field, by dropping a smallcylindrical magnet and to determine the value of magnetic moment of the magnet. into a coil.

1.2 INTRODUCTION:

If we drop a magnet through a coil, an emf is induced in the coil according to Faraday's law of electromagnetic induction. Here, such an experiment is done using expEYES kit. The plot of emf versus time has a specific shape with two peaks. A theoretical analysis of this graph is discussed here for both short and long cylindrical magnets. Mathematical expressions are derived for both. Knowing this equation, experiments to calculate the moment of a magnet can be devised. If we use a long conducting tube instead of a simple coil in this experiment, it can even help in measuring the eddy current damping coefficient k

1.3 MATHEMATICAL FORMULA:

The induced emf is given by the formula:

$$\begin{aligned}\text{emf} &= -\frac{NAm\mu_\text{o}}{4\pi l}gt\left[\left(R^2+\left(-z_\text{o}+\frac{1}{2}gt^2+l\right)^2\right)^{-\frac{3}{2}}\right.\\ &\left.-\left(R^2+\left(-z_\text{o}+\frac{1}{2}gt^2-l\right)^2\right)^{-\frac{3}{2}}\right]\end{aligned}$$

Here, μ_0 = Permeability of free space.
m = magnetic moment of the magnet.
N = Number of turns in the coil
A = Crosssectional area of the coil.
z_0 = The distance from which the magnet is dropped.
t = time after the magnet is dropped.
R = radius of the coil.

1.4 CIRCUIT DIAGRAM:

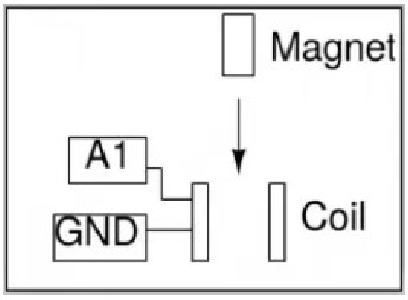

Figure 1: Experimental Set up

1.5 APPARATUS:

- expEYES-17.
- 2. Desktop having expEYES software installed.
- One coil of 300 turns
- One magnet.
- One Breadboard.
- Connecting wires.

1.6 Observations

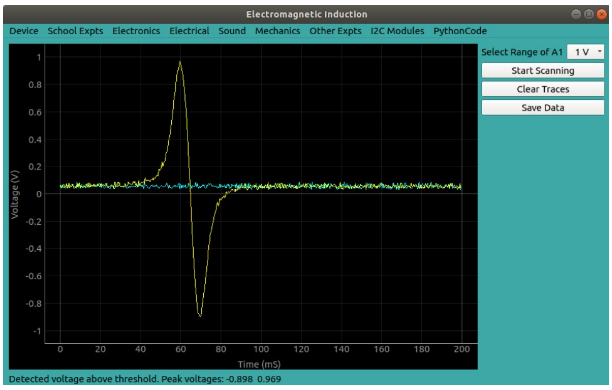

Figure 2: Variation of induced emf with respect to time recorded in expEYES software

1.7 ANALYSIS:

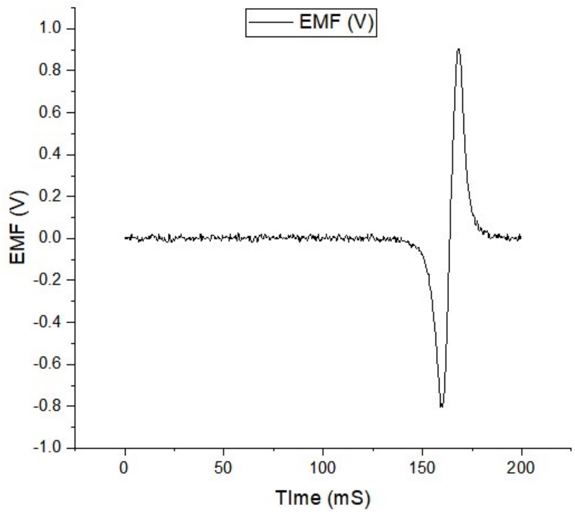

Figure 3: Plot for Induced EMF(V) vs time(ms) from the collected data

Observed Parameters: turns = 129
diameter of the tube =1.19 cm = 0.0119 m
2l (the length of the magnet), = 0.909 cm
so, l = 0.454 cm

From the graph it is seen that at time 159.2 ms the value of emf is −0.806 Volt and at time 169.0 ms emf is 0.903 Volt.

At minimum point using the equation the magnetic moment is found 44.023 Amp. m^2 and at maximum point the magnetic moment of the magnet is 73.69Amp.m^2.
Taking average of these two the magnetic moment is 58.85 Amp. m^2

1.8 CONCLUSION:

The value of magnetic moment of the magnet obtained from this experiment is 58.85 Amp. m^2.

2 Study of Operation of a Photo-Transistor

2.1 OBJECTIVE:

To study the output behavior of a photo transistor when a square wave of certain frequency is given to the input through a LED.

2.2 THEORY:

The phototransistor is a device that is able to sense light levels and alter the current flowing between emitter and collector according to the level of light it receives.Phototransistors and photodiode scan both be used for sensing light, but the phototransistor is more sensitive in view of the gain provided by the transistor. This makes phototransistors more suitable in a number of applications.

2.3 CIRCUIT DIAGRAM:

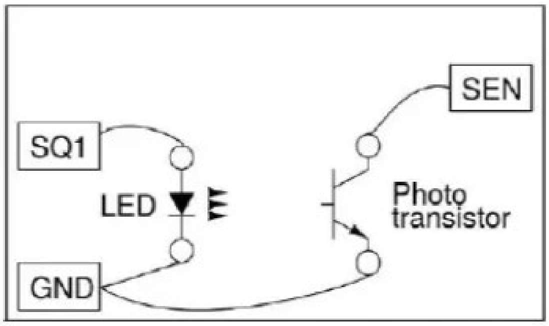

Figure 4: Experimental Setup

2.4 APPARATUS:

- expEYES-17.
- 2. Desktop having expEYES software installed.
- One Breadboard.
- Connecting wires.
- One LED

2.5 OBSERVATION:

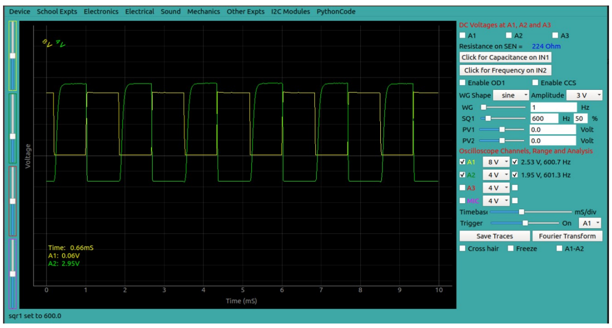

Figure 5: Output waveform

2.6 DISCUSSION:

We prefer a transistor over a diode for our experiments.
The reasons are the following:
1. Diode is an uncontrollable switch, which is switched on beyond cut a cutoff voltage and switched off below cut in voltage. Wheareas a Transistor can be controlled when to conduct which makes transistor a controllable switch.
2. The diode is a semiconductor device which allows the current to flow only in one direction, whereas the transistor transfers the resistance from the low resistance region to high resistance region.

2.7 CONCLUSION:

There is a 180° phase difference between input and output waveform.

3 Study of IC-555 as a multivibrator

3.1 OBJECTIVE:

To design and study the astable multivibrator circuit using IC 555

3.2 INTRODUCTION & THEORY:

Individual Sequential Logic circuits can be used to build more complex circuits such as Counters, Shift Registers, Latches or Memories etc, but for these types of circuits to operate in a "Sequential" way, they require the addition of a clock pulse or timing signal to cause them to change their state. Clock pulses are generally square shaped waves that are produced by a single pulse generator circuit such as a Multivibrator which oscillates between a "HIGH" and a "LOW" state and generally has an even 50% duty cycle, that is it has a 50% "ON" time and a 50% "OFF" time. Sequential logic circuits that use the clock signal for synchronization may also change their state on either the rising or falling edge, or both of the actual clock signal. Astable state has NO stable states but switches continuously between two states this action produces a train of square wave pulses at a fixed frequency.

The 555 timer IC was first introduced around 1971 by the Signetics Corporation as the SE555/NE555 and was called "The IC Time Machine" and was also the very first and only commercial timer IC available. It provided circuit designers with a relatively cheap, stable, and user-friendly integrated circuit for timer and multivibrator applications. These ICs come in two packages, either the round metal-can called the 'T' package or the more familiar 8-pin DIP 'V' package as shown in figure below. The IC comprises of 23 transistors, 2 diodes and 16 resistors with built-in compensation for component tolerance and temperature drift.

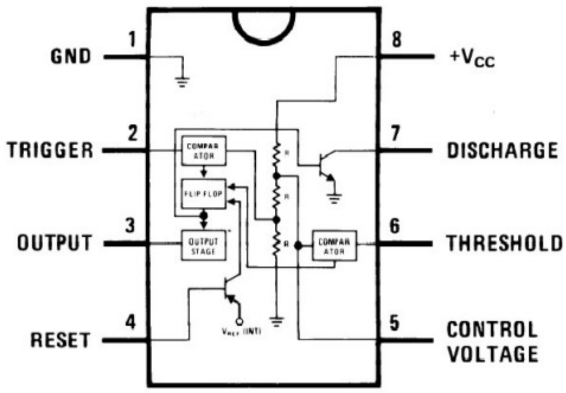

Figure 6: IC 555 in 8-pin DIP package

The 555 can operate in either mono/bi-stable or astable mode, depending on the connections to and the arrangement of the external components. Thus, it can either produce a single pulse when triggered, or it can produce a continuous pulse train as long as it remains powered.

Astable multivibrator circuits are not stable in any state and switch outputs after predetermined time periods. The result of this is that the output is a continuous square/rectangular wave with the properties depending on values of external resistors and capacitors. Thus, while designing these circuits following parameters need to be determined:
1. Frequency (or the time period) of the wave.
2. The duty cycle of the wave.

For the waveforems, the time period of the pulse is defined as T and duration of the pulse (ON time) is τ. Duty cycle can be defined as the On time/Period that is, τ/T in the above figure. Obviously, a duty cycle of 50% will yield a square wave. The key external component of the astable timer is the capacitor. An astable multivibrator can be designed as shown in the circuit diagram (with typical component values) using IC 555 , for a duty cycle of more than 50%. The corresponding voltage across the capacitor and voltage at output is also shown. The astable function is achieved by charging/discharging a capacitor through resistors connected, respectively, either to $\mathrm{V_{CC}}$ or GND. Switching between the charging and discharging modes is handled by resistor divider $R1 - R3$, two Comparators, and an RS Flip-Flop in IC 555 . The upper or lower comparator simply generates a positive pulse if V_C goes above $2/3V_{CC}$ or below $1/3V_{CC}$. And these positive pulses either SET or RESET the Q output. The time for charging C from 1/3 to 2/3 Vcc, i.e, ON Time = $\mathbf{0.693\,(R_A + R_B)}$. C The time for discharging C from 2/3 to 1/3 Vcc, i.e. OFF Time = $\mathbf{0.693R_{.}}$. To get the total oscillation period, just add the two:

$$T_{\text{osc}} = 0.693 \cdot (R_A + R_B) \cdot C + 0.693 \cdot (R_B) \cdot C = 0.693 \cdot (R_A + 2 \cdot R_B) \cdot C$$

Thus,

$$\begin{aligned} f_{\text{osc}} &= 1/T_{\text{osc}} = 1.44/\left(R_A + 2 \cdot R_B\right) \cdot C \\ \text{Duty cycle} &= R_A + R_B/R_A + 2 \cdot R_B \end{aligned}$$

3.3 APPARATUS:

- expEYES-17.
- 2. Desktop having expEYES software installed.
- IC 555
- One Breadboard.
- Connecting wires.

3.4 CIRCUIT DIAGRAM:

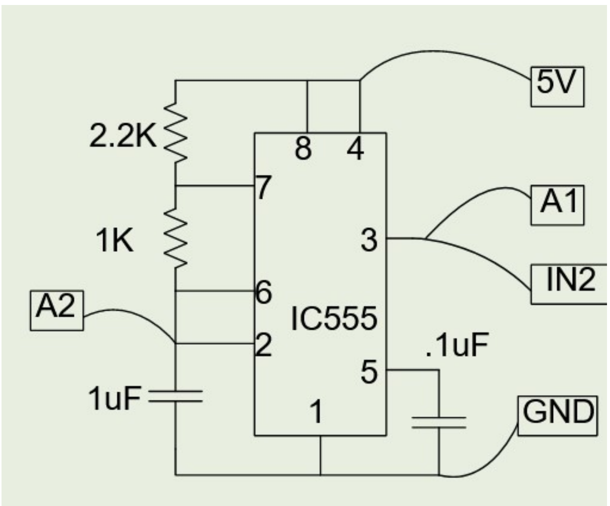

Figure 7: IC 555 wiring diagram

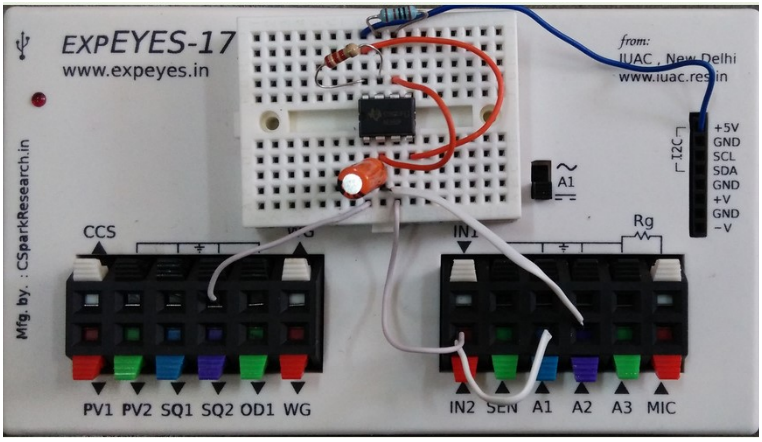

Figure 8: Photograph of the experimental setup

3.5 OBSERVATIONS CALCULATIONS:

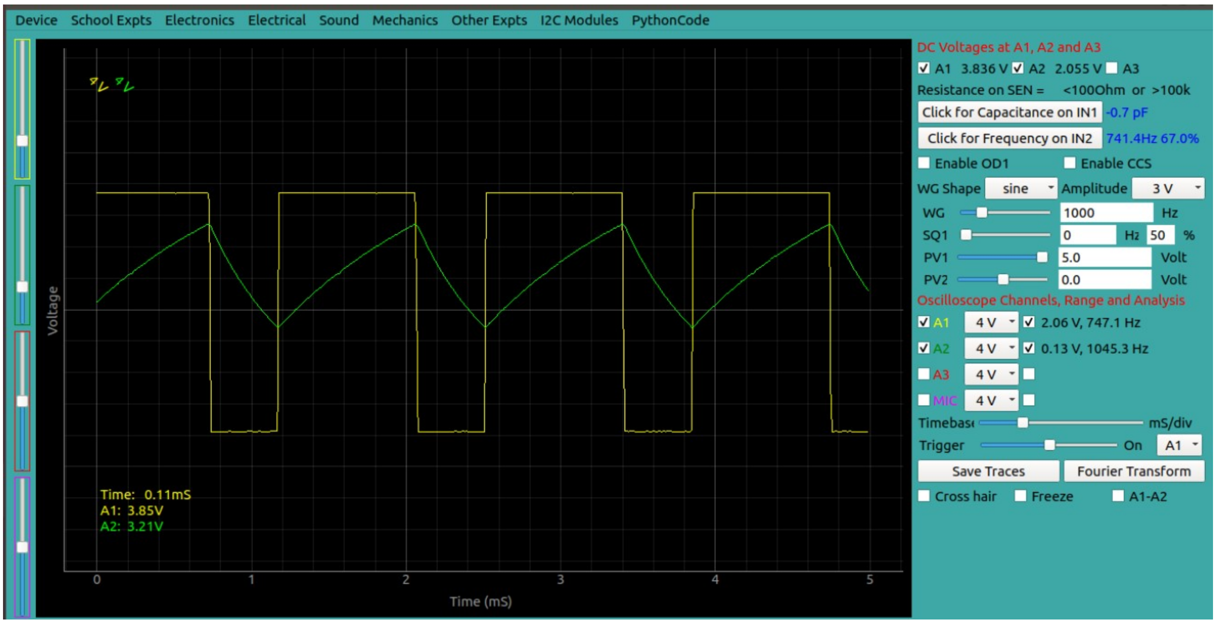

Figure 9: Picture of the oscilloscope program showing the IC555 output. The voltage across the capacitor is shown on A2.

We have used $R1 = 9.88$ K, $R2 = 2.1$ K, $C = 1uF$

The calculated frequency and duty cycle are 101.15 Hz and 84.70 % .

3.6 RESULTS & CONCLUSIONS:

We successfully designed and studied a multivibrator using IC 555.
The oscillation frequency is found to be 101.15 Hz and the duty cycle is found to be 84.70 % .

Part II

Lattice Dynamics

1 Abstract

Understanding the dynamics of Lattice vibrations is essential to understand the inter- action of electro-magnetic waves and crystalline solids. Lattice vibrations can be can be modelled as an oscillator. Considering the crystal to be made of an infinite spring mass system, important concepts like ACOUSTICAL MODE, OPTICAL MODE, ENERGY GAP, etc can be understood. This experiment aims to study lattice vibrations via an electrical simulation. An LC oscillator system can be used to study the same. The point is that both the LC circuit and a lattice of atoms (in the limit of small displace- ments) are harmonic oscillators, and as such, they obey similar dynamics. With just change the symbols to go from one system to the other, but the equations of motion are formally the same.

2 OBJECTIVE:

1. Study of the dispersion relation for the mono-atomic lattice-Comparison with theory.
2. Determination of the cut-off frequency of the mono-atomic lattice.
3. Study of the dispersion relation for the di-atomic lattice – ‘acoustical mode’ and ‘optical mode’ energy gap. Comparison with theory.

3 INTRODUCTION

Lattice dynamics is an essential component of any postgraduate course in physics and material science. In particular it is essential for understanding the interaction of electro-magnetic waves and crystalline solids. In general, students find it difficult to understand involved concepts like ACOUSTICAL MODE, OPTICAL MODE, ENERGY GAP etc., which they cannot see for themselves in the laboratory. Such a difficulty can be overcome by introducing a laboratory exercise in which the student follows a carefully prescribed procedure which presents him with a simplified model of the system and allows him to verify well established theories. In the process he gains an insight into the concepts. The lattice dynamics kit provides such an experience in the study of dynamics of mono and di-atomic lattices.
The following experiments may be performed with the help of the kit.
(i) Study of the dispersion relation for the mono-atomic lattice-Comparison with theory.
(ii) Determination of the cut-off frequency of the mono-atomic lattice.
(iii) Study of the dispersion relation for the di-atomic lattice - ’acoustical mode’ and ’opticle mode’ energy gap. Comparison with theory.

4 THEORY FOR MONOATOMIC LATTICE

Fig. shows a mass and spring model for a one dimensional mono-atomic lattice. The particles having mass ’ m ’ connected by spring of force constant ’f’.

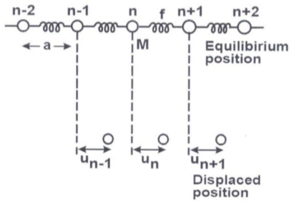

Figure 10: One-Dimensional linear mono-atomic lattice

$a \rightarrow$ lattice constant
$f \rightarrow$ Force constant
$M \rightarrow$ Mass of the atom
The equilibrium distance between the particles is ' a ' and the array is assumed to be infinitely long. Assuming only the nearest neighbour interaction, the equation of the motion of the nth atom is given by:

$$m\ddot{x}n = f\left(Un + 1 + U_{n-1}\right) - 2U_n$$

which when solved gives the angular frequency

$$\begin{aligned}\omega^2 &= \frac{4f}{m}\sin^2\left(\frac{ka}{2}\right)\\ &= \frac{2f}{m}(1-\cos\theta)\end{aligned}$$

where k is the wave vector $\left(\frac{2\pi}{\lambda} \text{ or } \frac{\omega}{c}\right)$ and c is the velocity of propagation and $\theta = ka$ is the phase change per unit cell. The relation shows that the velocity of propagation is dependent on frequency i.e., dispersion is indicated. It also shows that that there is a maximum frequency.

$$v_{\max} = \frac{\omega_{\max}}{2\pi} = \frac{1}{\pi}\sqrt{\frac{f}{m}}$$

beyond which no transmission occurs. The array may thus be considered as a low-pass filter which transmits only in the range $0 - v_{\max}$.

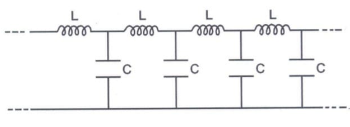

Figure 11: Electrical analogue of linear monoatomic lattice

. The dispersion relation for this circuit is

$$\omega^2 = \frac{2}{LC}(1-\cos\theta)$$

where θ is the phase change introduced by each section (unit cell) of the filter. Thus, one has a precise analogy with the one dimensional mono-atomic lattice, with $C \leftrightarrow m$ and $\left(\frac{1}{L}\right) \leftrightarrow f$. By measuring the phase difference between the input and output voltages of the circuit shown in Fig as a function of frequency, the dispersion relation may be verified.

5 THEORY FOR DIATOMIC LATTICE

The dispersion relations for the mechanical and electrical analogues are given below:

$$\omega^2 = f\left(\frac{1}{m}+\frac{1}{M}\right) + f\left[\left(\frac{1}{m}+\frac{1}{M}\right)^2 - \frac{4\sin^2\theta}{mM}\right]^{1/2}$$

(mechanical)

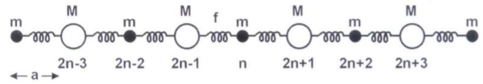

Figure 12: Linear diatomic lattice of lattice parameter 'a' mass 'm' and 'M' and force constant 'f'.

$$\omega^2 = \frac{1}{L}\left(\frac{1}{C}+\frac{1}{C_1}\right)+\frac{1}{L}\left[\left(\frac{1}{C}+\frac{1}{C_1}\right)^2-\frac{4\sin^2\theta}{CC_1}\right]^{1/2}$$

(electrical)

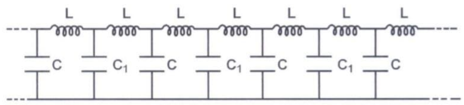

Figure 13: Electrical analogue of linear diatomic lattice

In contrast to the mono-atomic lattice, there are now two frequencies $\omega_+$and ω_- corresponding to a particular value of the wave vector **k**. In a plot of $\boldsymbol{v}$ verces θ, this leads to two branches; the one corresponding to $\boldsymbol{v}$. is called the acoustical branch and the one corresponding to $\boldsymbol{V}+$is called the optical branch. The frequency gap between the two branches depends on (**M**/m).

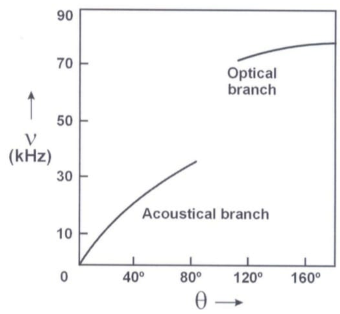

Figure 14: Dispersion relation for the diatomic lattice

6 OBSERVATIONS:

Frequency (kHz)	Phase(10 nos.)	Phase per unit	Frequency (kHz)	Phase(10 nos.)	Phase per unit
1	12	1.2	23	637	63.7
2	35	3.5	24	675	67.5
3	78	7.8	25	695	69.5
4	128	12.8	26	720	72
5	153	15.3	27	744	74.4
6	177	17.7	28	760	76
7	184	18.4	29	797	79.7
8	195	19.5	30	830	83
9	220	22	31	860	86
10	261	26.1	32	884	88.4
11	310	31	33	913	91.3
12	338	33.8	34	925	92.5
13	348	34.8	35	990	99
14	360	36	36	1020	102
15	375	37.5	37	1080	108
16	410	41	38	1112	111.2
17	453	45.3	39	1170	117
18	490	49	40	1210	121
19	514	51.4	41	1243	124.3
20	540	54	42	1276	127.6
21	549	54.9	43	1332	133.2
22	580	58	44	1440	144

Table 1: Frequency vs Phase for monoatomic lattice with 10 units.

7 ANALYSIS & CALCULATIONS:

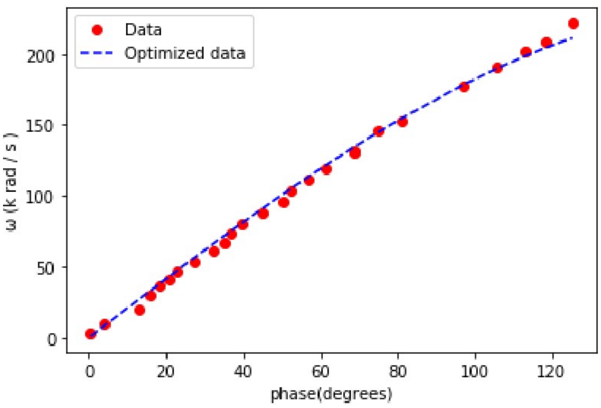

Figure 15: Dispersion relation of mono-atomic lattice. The fit parameter $a = 168.234 \pm 1.043 \text{krads}^{-1}$

Frequency (kHz)	Phase(5 units)	Phase per unit	Frequency (kHz)	Phase(5 units)	Phase per unit
4	170	34	21	856	171.2
5	199	39.8	22	-	-
6	233	46.6	23	-	-
7	281	56.2	24		-
8	325	65	25	-	-
9	360	72	26		-
10	393	78.6	27	-	-
11	443	88.6	28		-
12	499	99.8	29	-	-
13	540	108	30	-	-
14	582	116.4	31	-	-
15	649	129.8	32	1011	202.2
16	690	138	33	1080	216
17	740	148	34	1170	234
18	792	158.4	35	1263	252.6
19	822	164.4	36	1359	271.8
20	846	169.2	37	1457	291.4
21	856	171.2	38	1539	307.8

Table 2: Frequency vs Phase for diatomic lattice with 5 units.

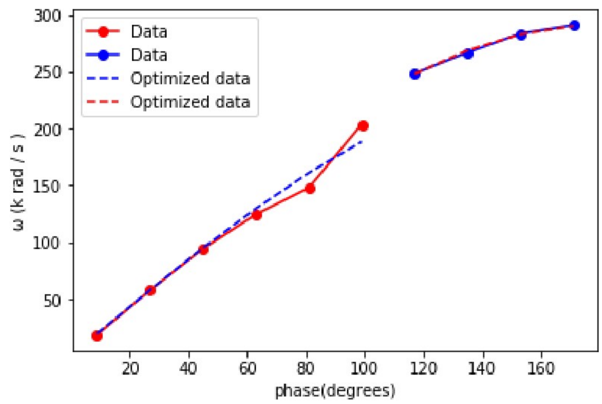

Figure 16: Dispersion relation of di-atomic lattice. The fit parameter $a = 168.234 \pm 1.043 \text{krads}^{-1}$

For Mono-atomic lattice:

Theoretical cutoff frequency,

$$\begin{aligned}\nu = \frac{\omega}{2\pi} &= \frac{1}{\pi}\sqrt{\frac{1}{LC}} \\ &= \frac{1}{\pi}\sqrt{\frac{1}{463.22 \times 10^{-6} \times 152.641 \times 10^{-9}}} \\ &= 45.861\text{kHz}\end{aligned}$$

From the data, the cutoff frequency

$$\begin{aligned}\nu = \frac{\omega}{2\pi} &= \frac{1}{\pi}\frac{a}{\sqrt{2}} \\ &= \frac{168.234}{\pi\sqrt{2}} \\ &= 45.823k \text{ Hz}\end{aligned}$$

Di-atomic lattice

Acoustic mode cutoff frequency of Di-atomic lattice,

$$= \frac{\omega}{2\pi} = \frac{1}{\pi}\sqrt{\frac{1}{LC_1}}$$
$$= 22.785\text{kHz}$$

Optical mode cutoff frequency of Di-atomic lattice,

$$\nu = \frac{\omega}{2\pi} = \frac{1}{\pi}\sqrt{\frac{1}{LC_2}}$$
$$= 31.231\text{kHz}$$

8 RESULTS & CONCLUSIONS

1. Experimental cutoff frequency for monoatomiic lattice vibrations: 45.823 kHz.
2. Theoretical cutoff frequency for monoatomiic lattice vibrations: 45.861 kHz.
3. The experimental value of the cutoff frequency of mono-atomic lattice matches with an high degree of accuracy with the predicted theoretical value.
4. Theoretical acoustical cutoff frequency for di-atomic lattice vibrations: 22.785 kHz.
5. Experimental acoustical cutoff frequency for di-atomic lattice vibrations: 22.144 kHz.
6. Theoretical optical cutoff frequency for di-atomic lattice vibrations: 31.231 kHz.
7. Experimental optical cutoff frequency for di-atomic lattice vibrations: 31.048 kHz