

Introduction

Progress in science is achieved through advances in both theory and experiments. Theoretical predictions must be verified by experiments and new experimental results leads to fresh theoretical developments. The role of experiment has become more significant due to the dominance of technology in our lives. Nowadays the ability to convert progress in science to technological products decide the future of any nation. This capability can only be achieved by making science education strong in both theory and experiment, which demands good laboratory facilities. Over the past several years, the laboratory facilities at Indian universities have declined instead of keeping updated. The advent of cost effective personal computers have made some impact in modeling and simulation of experiments but they are not substitutes for actual experiments.

In any experiment, several physical parameters are measured, under certain conditions. The experimental setup will have sensor elements to measure the parameters, control elements to alter them and recording/display subsystems to handle the generated data. Equipment for doing a specific experiment is made by selecting the required sensor/control elements and putting them together permanently in a specific way. Alternate method is to use a computer to integrate the sensor/control elements and manage them using software. This approach will reduce overall costs if the same setup can be configured for doing different experiments. Once the interfacing hardware and software are in place, one can connect any sensor element to it and take the measurements through software. Storage and analysis of data also becomes easier and more flexible.

Phoenix is a modular, extensible and cost effective hardware plus software framework for developing computer interfaced science experiments. Coupled with a computer, it can effectively replace a large number of equipment and enable one to carry out a variety of experiments using the same inexpensive hardware, of course by using different sensor elements and software. Phoenix enables students and teachers to design new experiments or to demonstrate various scientific principles, without getting into the details of electronics or computer programming. The power of personal computers has been effectively utilized for experiment control, data acquisition and mathematical analysis of data, with the help of simple and modular software. The system supports experiments at different levels of complexity. The following paragraphs describe the architecture, present status and several experiments performed using Phoenix.

A photograph of the basic hardware unit is shown in figure . The sockets on the top panel of the Phoenix interface box acts as gateways between the computer and the outside world. Voltage levels at the sockets can be controlled/monitored, as a function of time, issuing simple commands or using a graphical user interface . Experiments are conducted by connecting appropriate control/sensor elements to the sockets and managing the overall operation under software control. Phoenix has been designed to cater to different levels of sophistication, using a modular design in both hardware and software. For example, it can do a simple experiment like capturing the voltage waveform induced across a coil, by a moving magnet, to a complex one like measuring the energy spectrum of alpha particles from a radioactive source.

Science, a fundamentally open-ended and exploratory activity, is often taught as a collection of "facts" that many students get repelled from science, and most are deprived of an opportunity to strengthen and reinforce their own inclination to experiment, question, and explore the outside world. Phoenix based experiments are exploratory and open ended. This document contains several experiments done using the Phoenix Kit. It is not a conventional laboratory manual where you find everything specified to the minute details. Experiments are divided into different sections according to the topic.

Mechanics

Chapter 1

Acceleration due to Gravity

In this chapter, we measure the value of acceleration due to gravity g by different methods. First, we calculate g by measuring the time taken by an object to fall freely under gravity, through a known distance. In the second method, we measure the time periods of two different kinds of pendula, and calculate g from them.

1.1 Value of g from Time of Free Fall

1.1.1 Theory

The motion of an object under gravity is governed by the relation

$$s = ut + \frac{1}{2}gt^2 \quad (1.1)$$

where s is the height from which the object falls, u the initial velocity of the object, g the acceleration due to gravity, and t the time taken. So, if we can accurately measure the time taken by an object with a known initial velocity, to fall through a known height, the acceleration due to gravity can be directly found from this relation. If the object is initially at rest, i.e. $u = 0$, the relation reduces to

$$s = \frac{1}{2}gt^2 \quad (1.2)$$

1.1.2 Apparatus

We need to drop a spherical object of high density material from a known height and measure the time taken to reach ground. High density required to reduce the effect of air resistance and spherical shape to avoid any dependance on the change in orientation while falling. The object has to be released under computer control and the arrival of it on ground also need to be sensed. We have used a metal ball of about 2 cm diameter that is magnetically held by a solenoid [specifications]. The solenoid is attached to a clamp, which can slide along a metallic meter scale mounted vertically as



Figure 1.1: Apparatus

shown in figure 1.1. The accuracy of height measurement is around one fifth of a millimeter. For better accuracy one can use a height gauge with vernier attachment, giving an accuracy of 0.02 mm.

When the ball is released from the solenoid it falls on the metal base at the bottom. A loudspeaker is attached to the base to capture the signal generated due to the vibrations created by the impact. The loudspeaker output is connected to Phoenix.

1.1.3 Procedure

1. Connect the solenoid between Digital Output D0 and GND.
2. Connect the loudspeaker between the input of the non-inverting amplifier and GND.
3. Set the gain resistance R_g to 100Ω .
4. Connect the amplifier output to Digital Input D0, through a $1\text{ K}\Omega$ resistor.
5. Start the python program *gravity.py*.
6. Mount the solenoid on the vertical scale at the desired height and attach the ball.
7. Enter the height and release the ball using software.
8. Repeat the procedure for different heights.

1.1.4 Observations and Analysis

The fall time is measured for different heights. The height is measured from the top of the surface on which the ball falls to the bottom of the ball, when it is held by the solenoid. The results are shown in table 1.1.

Height $h(\text{cm})$	Time $t(\text{s})^*$	Time $t'(\text{s})^{**}$	$g = \frac{2h}{t^2}(\text{cm/s}^2)^*$	$g' = \frac{2h}{t'^2}(\text{cm/s}^2)^{**}$
93.13	0.4386	0.4366	968.2	977.1
88.13	0.4265	0.4245	968.9	978.1
83.13	0.4142	0.4122	969.1	978.5
78.13	0.4017	0.3997	968.4	978.1
73.13	0.3887	0.3867	967.6	977.6
68.13	0.3753	0.3733	967.3	977.7
63.13	0.3613	0.3593	966.9	977.7
58.13	0.3469	0.3449	965.7	976.9
53.13	0.3317	0.3297	965.8	977.5
48.13	0.3160	0.3140	963.6	975.9
43.13	0.2993	0.2973	962.7	975.7
38.13	0.2811	0.2791	964.9	978.8
33.13	0.2623	0.2603	962.6	977.5
28.13	0.2418	0.2398	961.6	977.7
23.13	0.2198	0.2178	957.3	974.9
18.13	0.1945	0.1925	957.7	977.7
13.13	0.1660	0.1640	952.6	976.0
8.13	0.1311	0.1291	945.1	974.6

Table 1.1: Height Vs fall time and calculated values of 'g'.

*With the 2 ms correction applied

**With an additional correction of 2 ms

The value of 'g' calculated using the expression 1.2 results in lower values of 'g' ball is not released instantaneously, due to the magnetic retentivity of the solenoid. This delay is found to be around 2 milliseconds and is subtracted from the fall time. However the calculated 'g' shows better agreement with the actual value if a correction of 4 milliseconds is applied. The source of the additional 2 ms delay could be from the sensor. The next section describes a better method of analyzing the data, by mathematically eliminating the systematic errors.

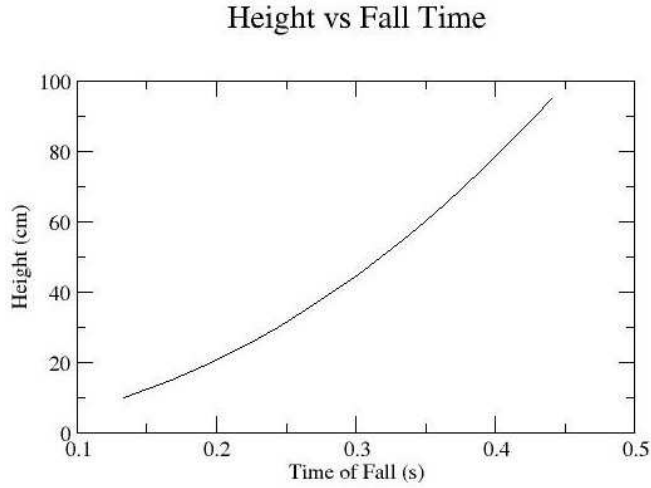


Figure 1.2: Height-Vs-Time.

1.1.5 Alternate method of Data Analysis

In this method, we need not utilize the known relationship between the distance travelled, time taken and the value of 'g'. We just express the distance as an arbitrary polynomial function of time and extract the coefficients by fitting with the experimental data.

$$s = a_0 + a_1t + a_2t^2 \quad (1.3)$$

From the definition of acceleration, we know that it is nothing but the second derivative of distance with respect to time. Differentiating 1.3 twice with respect to t, gives

$$acceleration = \frac{d^2s}{dt^2} = 2a_2$$

The experimental data is shown in figure 1.2 . The curve fitting is done using the program *xmgrace* , the details of which are given in appendix A. The value of the coefficient a_2 is 489.878, as shown in figure 1.3, which gives the value of acceleration to be 979.76 cm/s^2 , which is very close to the accepted standard of 981 cm/s^2 .

1.1.6 Result

The value of g was found out by two methods:

1. On calculating directly from the data, a range of values was obtained.
2. On performing a curve fit, g was found to be 979.76 cm/s^2 .

1.1.7 Inference

The values of g calculated directly from the data after accounting for the retentivity of the solenoid are much smaller than the actual value, and show a gradation with respect to height. This means that there is some more systematic delay to be accounted for. On applying a further correction of 2 ms, this gradient vanishes! This indicates that the further delay is around 2 ms. We can only guess as to the sources of this delay. It could be due to a delay in the response of the speaker or some other components in the detecting circuit.

The beauty of the method of curve fitting as a tool for analysis, lies in the fact that all systematic errors are taken care of, by the coefficients a_0 and a_1 .

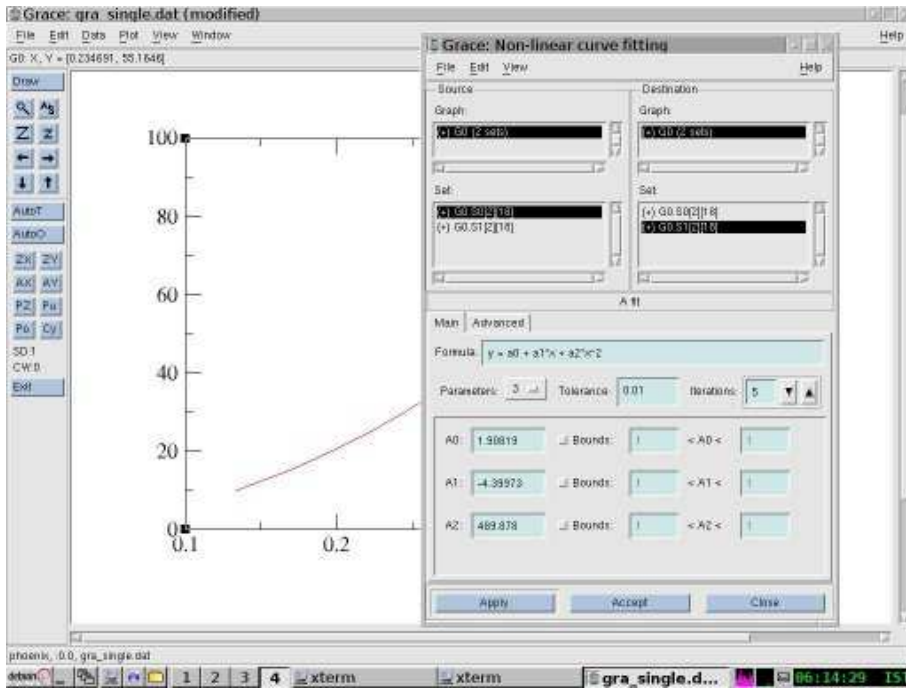


Figure 1.3: Fitting the curve

1.2 Value of g from Period of Pendulum

In this section we will describe how to measure the period of a Rod Pendulum and a Combinational Physical pendulum and calculate the value of g from it. Simple pendulum has been excluded since the level of accuracy is limited by its wobbling nature.

1.2.1 Theory

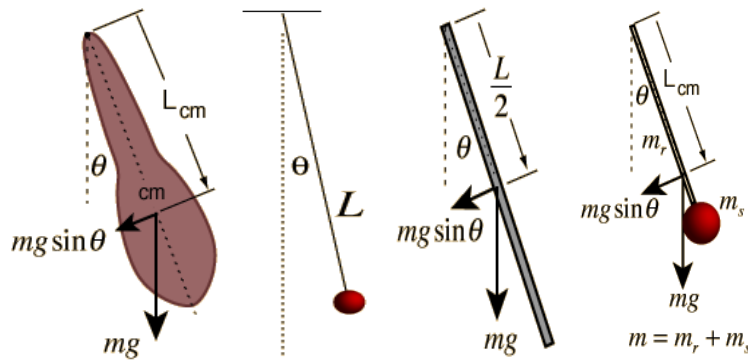


Figure 1.4: Different types of pendula. (a) Physical Pendulum of arbitrary shape. (b) Simple pendulum. (c) Rod Pendulum. (d) Physical Pendulum combining a rod and a ball.

A body of mass suspended about an axis constitutes a pendulum. For small amplitudes of oscillation, the period of oscillation depends on the following factors:

- Moment of Inertia of the body about the axis of suspension, I_a
- The distance from the point of suspension to the centre of mass of the body, L_{cm}
- The value of acceleration due to gravity, g

and is given by the equation

$$T = 2\pi\sqrt{\frac{I_a}{mgL_{cm}}} \quad (1.4)$$

where m is the mass of the body. Equation 1.4 is valid for a pendulum of any arbitrary shape. For certain geometrical shapes like sphere, cylinder etc., the moment of inertia I_a is given by simple equations.

1.2.1.1 Simple Pendulum

A simple pendulum is one which can be considered to be a point mass suspended from a string or rod of negligible mass, refer to figure 1.4(b). The period of oscillation is given by the equation

$$T = 2\pi\sqrt{\frac{L}{g}} \quad (1.5)$$

Value of g can be calculated by measuring period T .

1.2.1.2 Rod Pendulum

Moment of Inertia of a uniform rod about one of its ends is given by $I_a = \frac{1}{3}mL^2$. Substituting this in 1.4 gives

$$T = 2\pi\sqrt{\frac{\frac{1}{3}mL^2}{mg\frac{L}{2}}} = 2\pi\sqrt{\frac{2L}{3g}} \quad (1.6)$$

where L is the length of the rod, and g is the acceleration due to gravity.

1.2.1.3 Combinational Physical Pendulum

A physical pendulum composed of a uniform rod with a sphere on the end of it, as shown in figure 1.4(d), is an example of a combination physical pendulum. Substituting the moments of inertia of the rod and the ball in to equation 1.4 gives

$$T = 2\pi\sqrt{\frac{m_r\frac{L^2}{3} + \frac{2}{5}m_sR^2 + m_s(L+R)^2}{g[m_r\frac{L}{2} + m_s(L+R)]}} \quad (1.7)$$

where T is the time period of the pendulum, m_r the mass of the rod, m_s the mass of the ball, L the length of the rod, R the radius of the ball and g the acceleration due to gravity.

1.2.1.4 Large Amplitude Effects

For oscillations with small amplitudes, period is given by equation 1.4. But this relation is valid only for small amplitudes, since it assumes $\theta = \sin\theta$. For large amplitudes, the expression for time period is,

$$T = 2\pi\sqrt{\frac{I_a}{mgL_{cm}}} \left(1 + \frac{1}{16}\theta_o^2 + \frac{11}{3072}\theta_o^4 + \dots \right) \quad (1.8)$$

The correction is nearly one percent for $\theta = 22^\circ$.

1.2.2 Apparatus

- A rod pendulum is made by suspending a uniform cylindrical rod on a knife edge fixed perpendicular to one of its ends.
- A metal ball fixed to a thin rod makes up the combination physical pendulum, with a knife edge fixed to the rod, as in the earlier case.

The pendulum is mounted between two horizontal metal bars fixed on a clamp, such that it can freely oscillate. A light barrier, connected to Phoenix, is kept at the base in such a way that the pendulum intercepts the light during each oscillation. A scale is fixed horizontally on the light barrier to measure the approximate amplitude of oscillation.

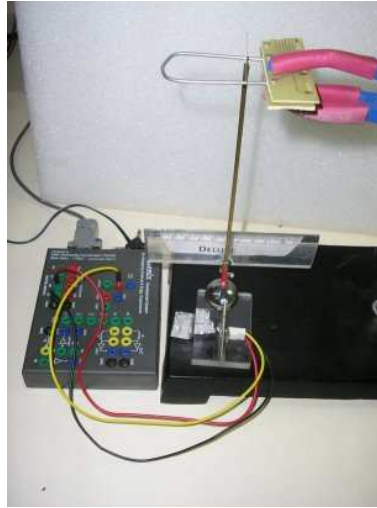


Figure 1.5: Apparatus

1.2.3 Procedure

1. Measure the dimensions of the pendulum and note them down.
2. Place the light barrier on the base and connect it to Phoenix as shown in figure 1.5.
3. Mount the pendulum on the bars and fix the clamp at a height such that the rod intercepts the light barrier while oscillating.
4. Make sure that the pendulum is vertical.
5. Allow the pendulum to come to rest, and adjust the position of the light barrier such that it is exactly at the mean position of the pendulum.
6. Set the pendulum in motion.
7. Start the Python program *rodpend.py* or *phys_pend.py*. For each oscillation, it will print a serial number, measured time period and the calculated 'g'.
8. For every 5 mm decrease in amplitude, note the scale reading and the serial number at that point.

1.2.4 Observations and Analysis for Rod Pendulum

The results obtained from the rod pendulum, having a length of 20.54 cm, are shown in figure 1.6. The value of 'g' is estimated using the equation:

$$g = 4\pi^2 \frac{2L}{3T^2} \quad (1.9)$$

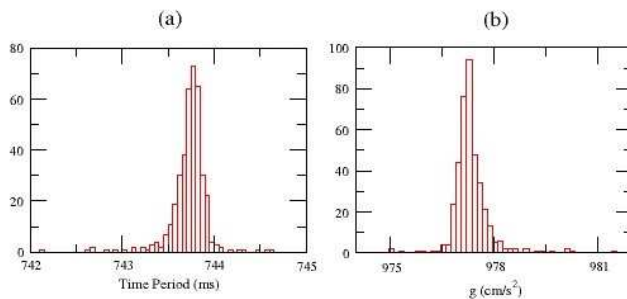


Figure 1.6: (a)Time period and (b) g plotted against frequency of occurrence

$$T = 743.768 \pm 0.097 \text{ ms}$$

$$g = 977.3 \pm 0.215 \text{ cm/s}^2$$

1.2.5 Observations and Analysis for Combination Pendulum

The value of g in the case of combination pendulum, is given by the equation:

$$g = 4\pi^2 \frac{m_r \frac{L^2}{3} + \frac{2}{5} m_s R^2 + m_s (L+R)^2}{T^2 [m_r \frac{L}{2} + m_s (L+R)]} \quad (1.10)$$

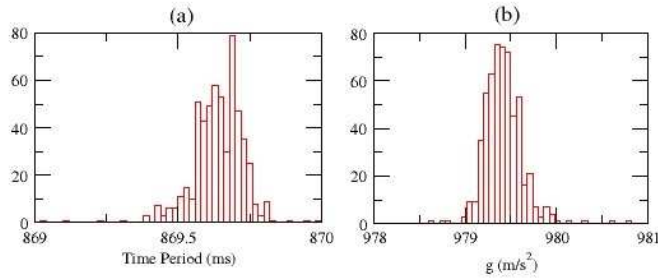


Figure 1.7: (a) Time Period and (b) g plotted against frequency of occurrence

Dimensions:

$$L = 17.9 \text{ cm}$$

$$R = 1.27 \text{ cm}$$

$$m_r = 9.25 \text{ grams}$$

$$m_s = 66.93 \text{ grams}$$

The results obtained are shown in figure 1.7.

$$T = 869.682 \pm 0.085 \text{ ms}$$

$$g = 979.39 \pm 0.21 \text{ cm/s}^2$$

1.2.5.1 Large Amplitude Effects

Amplitude (deg)	Theoretical Time Period (ms)	Measured Time Period (ms)
11.46	871.738	871.778
9.55	871.071	871.072
7.64	870.526	870.540
5.73	870.102	870.102
3.82	869.800	869.771
1.91	869.619	869.621

Table 1.2: Large Amplitude effects

For each value of amplitude, the average of ten readings of the time period is noted (refer table 1.2). These values are plotted against the amplitude expressed in degrees, as shown in figure 1.8. On fitting this data with the curve

$$T = T_o \left(1 + \frac{1}{16} \theta^2 + \frac{11}{3072} \theta^4 \right) \quad (1.11)$$

we get the value of T_o , the time period of the pendulum as the amplitude tends to zero, to be 869.563 ms.

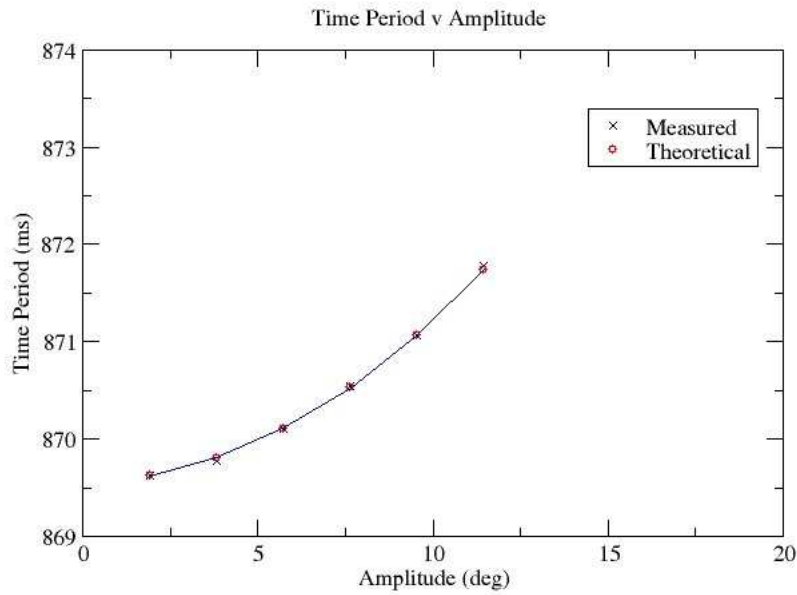


Figure 1.8: Time period depends on Amplitude

1.2.6 Result

- Value of acceleration due to gravity, g was found to be
 - $977.3 \pm 0.215 \text{ cm/s}^2$ in the case of rod pendulum.
 - $979.39 \pm 0.21 \text{ cm/s}^2$ in the case of combination pendulum.
- The time period of the combination pendulum was measured for different values of amplitude, and compared with the theoretical values.

1.2.7 Inference

In the case of rod pendulum, any irregularities in the distribution of mass would give rise to a reasonably large error, since the mass is spread over a greater volume than in the case of a combination pendulum, in which majority of the mass is concentrated at one end. Perhaps this could explain the better results obtained with the combination pendulum.

Chapter 2

Capacitor

2.1 Measurement of Capacitance

In this chapter, we will study different kinds of capacitors, by observing their charging/discharging characteristics, in series with a resistor.

2.1.1 Theory

A capacitor consists of two conducting plates separated by an insulator. The capacitance of a capacitor is a measure of the amount of charge it can hold for a given voltage across its terminals. The value of its capacitance depends on:

- The cross sectional area of the conducting plates, A
- Thickness of the insulating layer, d
- Dielectric constant of the insulator, k

and is given by the equation

$$C = k \frac{\epsilon_0 A}{d} \quad (2.1)$$

where ϵ_0 is the permittivity of free space.

When a capacitor is discharged through a resistor, the voltage across its terminals varies with time according to the relation

$$V(t) = V_0 e^{-\frac{t}{\tau}} \quad (2.2)$$

where $\tau = RC$ = time constant, V_0 the initial voltage across the capacitor's terminals, R the resistance and C the capacitance. So, if we can find the time taken by the capacitor to discharge to $\frac{1}{e}$ times its initial voltage, that gives the time constant, from which we can find the capacitance directly as

$$C = \frac{\tau}{R} \quad (2.3)$$

2.1.2 Apparatus

To measure the voltage across the capacitor, we connect it between CH0 and GND. A resistor is connected from digital output D3 to CH0, so that we can charge and discharge the capacitor by changing the voltage level at D3. Measurements are done using capacitors having different values. The value of R is chosen such that the time constant RC is in the order of few milliseconds.

2.1.3 Procedure

1. Find the exact value of resistance of the resistor using a multimeter.
2. Connect the free end of the resistor to Digital Output D3.
3. Connect the capacitor between ADC CH0 and GND.
4. From the main menu, start 'Phoenix->Experiments'.

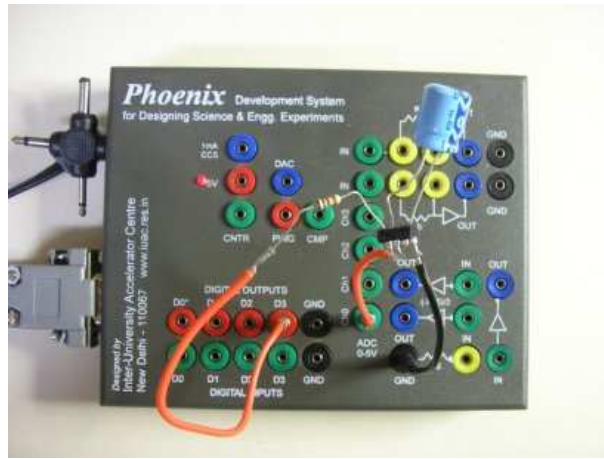


Figure 2.1: Apparatus

5. From the 'Physics' dropdown menu, select 'Capacitor Charging'.
6. Click on 'Discharging' to plot the voltage across the capacitor while discharging, and save it to a file named 'cap.dat'.

2.1.4 Observations & Analysis

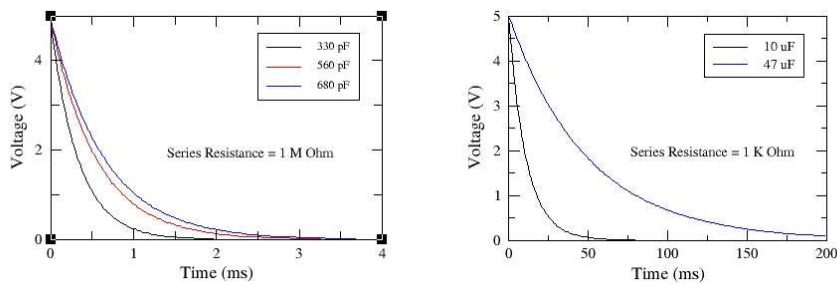


Figure 2.2: Discharging curves of different capacitors

The data is plotted, as shown in figure 2.2, and fitted onto the curve

$$y = a_0 e^{-\frac{x}{a_1}} + a_2 \quad (2.4)$$

The value of τ obtained for each capacitor, and the value of capacitance for each capacitor¹, are given in table 2.1.

Sl No.	Series Resistance	Time Constant $\tau(ms)$	Measured Capacitance	Printed value
1	1 M Ω	0.332	322 pF	330 pF
2	1 M Ω	0.552	542 pF	560 pF
3	1 M Ω	0.647	637 pF	680 pF
4	1 K Ω	11.04	11.04 μF	10 μF
5	1 K Ω	49.55	49.55 μF	47 μF

Table 2.1: Measured values of Capacitance

¹There is an ADC input capacitance of around 10 pF in parallel, so when measuring capacitances of the order of pF, we have to subtract it from the measured value.

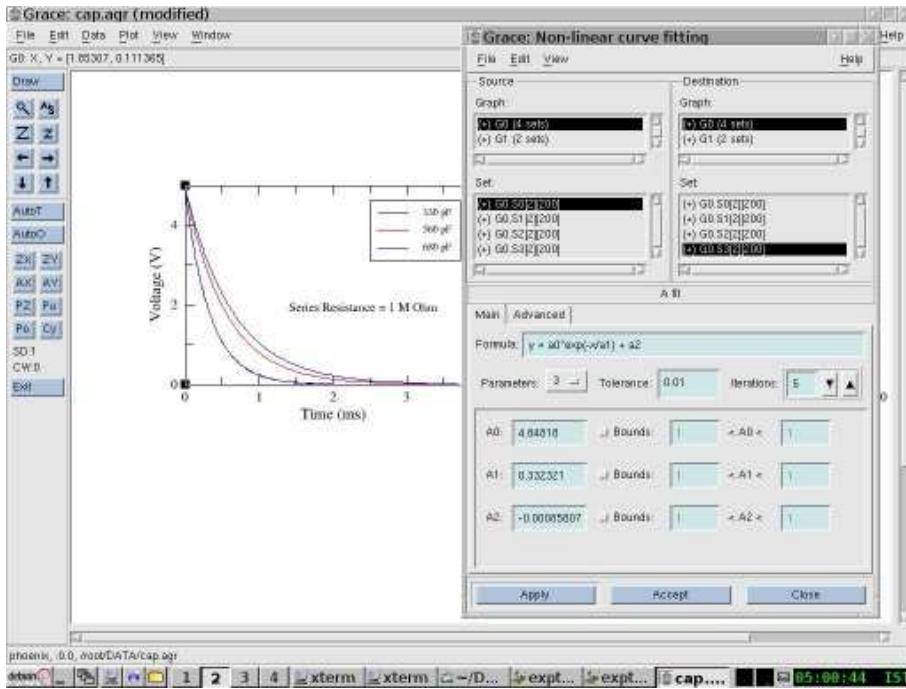


Figure 2.3: Fitting the curve gives $a_1 = 1.0271$

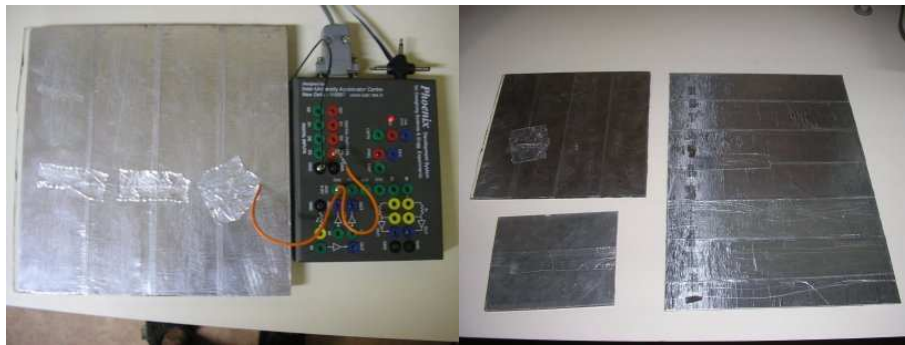


Figure 2.4: Apparatus

2.1.5 Result

The values of capacitance of five different capacitors were measured, and found to be within the tolerance limits of the specified value.

2.2 Dielectric Constant of Glass

In this section, we will make a capacitor from a piece of glass by pasting aluminium foil on both sides, and measure its capacitance, to estimate the value of dielectric constant of glass.

2.2.1 Theory

From equation 2.1, the value of dielectric constant k of the insulator in a capacitor of capacitance C , is given by

$$k = \frac{C}{\left(\frac{\epsilon_0 A}{d}\right)} \quad (2.5)$$

where A is the cross sectional area of the conducting plates, d the thickness of the insulating layer, and ϵ_0 the permittivity of free space.

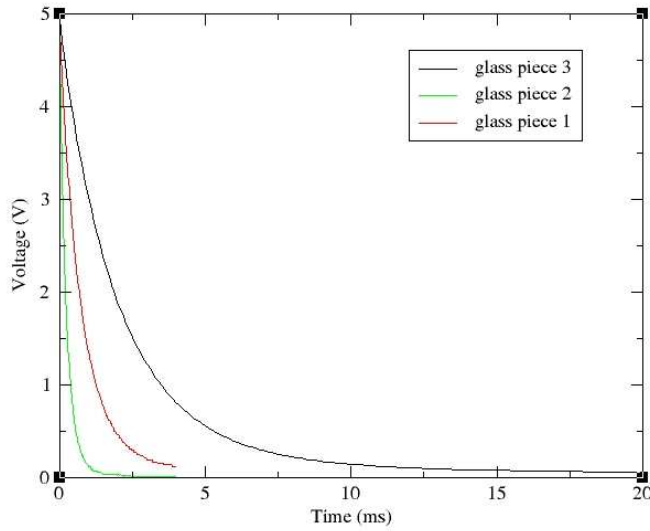


Figure 2.5: Discharging curves of the glass capacitors

Glass Piece no:	1	2	3
Area $A(m^2)$	0.0386	0.0137	0.0777
Thickness $d(mm)$	3.64	4.00	2.60
Capacitance $C(nF)$	0.746	0.235	2.08
Dielectric Constant k	7.84	7.75	7.86

Table 2.2: Dielectric constant measured for the three glass pieces

2.2.2 Apparatus

We take a rectangular piece of glass and paste aluminium foil on both faces, such that they are covered completely. Care should be taken to ensure that the coating on the two faces do not touch each other at any point. Attach wires to both faces, and our home made capacitor is ready!

Now connect the glass capacitor to Phoenix, in series with a $1\text{ M}\Omega$ resistance (so that the time constant is in the order of milli seconds), as in the earlier experiment.

2.2.3 Observations and Analysis

Observations were carried out with three glass pieces, of different sizes. Their dimensions are given in table

2.2

The discharging curves of both capacitors are shown in figure 2.5. Fitting with equation 2.4

2.2.4 Result

The value of dielectric constant was measured to be around 7.8, which closely agrees with the theoretical value.

Chapter 3

Sound

Let us now carry out a few experiments to study the propagation of sound in air. First, we measure the speed of sound using 40 kHz piezo electric crystals.

3.1 Speed of Sound using 40 kHz piezo

In this section, we will calculate the speed of sound, by measuring the time taken for a 40 kHz ultrasonic sound wave, to travel over a set of known distances.

3.1.1 Theory

Piezoelectricity is the ability of some materials to generate an electric potential in response to an applied mechanical stress, and vice versa. In this experiment, we use a pair of piezoelectric crystals whose resonant frequency is 40 kHz . One acts as the transmitter, and gives a 40 kHz ultrasound wave for a short period of time, on being given a pulse excitation. This wave is detected by the piezoelectric receiver, and the time taken for the ultrasound to travel from the transmitter to the receiver is measured.

This measurement is carried out for different distances, and the distance is plotted against time. The slope of this plot gives the velocity of sound in air.

3.1.2 Apparatus

A 40 kHz piezoelectric transmitter/receiver pair is taken, and the receiver is fixed on one end of a 15 cm metal scale. The transmitter is mounted on a magnet, so that it can be fixed at any desired position along the scale (refer figure). The transmitter is connected between Digital Output D3 and GND, while the receiver output is amplified and fed to the Digital Input D3, through a $1\text{ K}\Omega$ resistor.

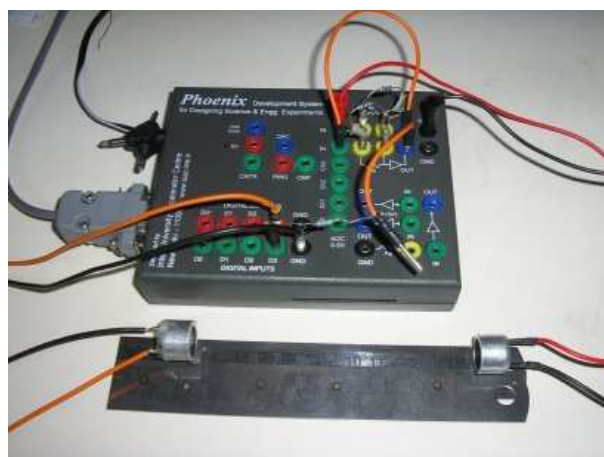


Figure 3.1: Apparatus

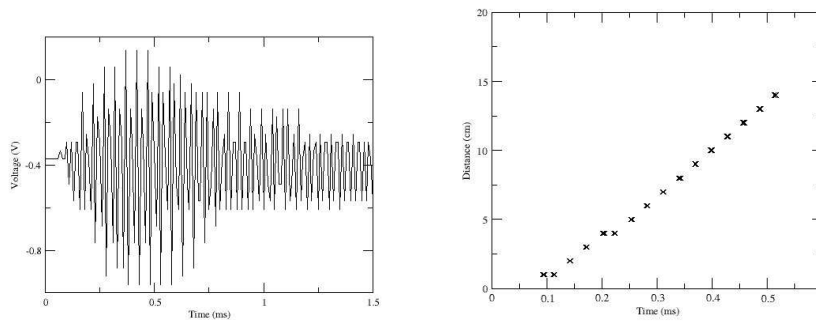


Figure 3.2: (a) Response of the receiver to an impulse at the transmitter and (b) plot of distance against time

3.1.3 Procedure

1. Connect the piezo transmitter between Digital Output D3 and GND.
2. Connect the receiver between the input of an inverting amplifier, and GND.
3. Set the gain resistance to $100\ \Omega$.
4. Connect the output of the amplifier to Digital Input D3, through a $1\ K\Omega$ resistor.
5. Run the program *sound.py* and take readings for different points.

3.1.4 Observations and Analysis

First, let us take a look at the signal detected by the receiver when a small pulse is given to the transmitter (figure 3.2). You can see that the signal builds up in strength quickly, attains a peak and then gradually dies down. To measure the time taken by sound to travel, we measure the time elapsed after a pulse is given at the transmitter, till a HIGH is detected at the Digital Input D3.

Since the Digital Inputs detects a HIGH only when the voltage is above a certain threshold value, the triggering of the Digital Input might take place only a few microseconds after the signal has actually reached the receiver, after it has built up in strength.

Now, as we move the two crystals farther away from each other, the amplitude of the detected signal becomes progressively smaller. So, at some point, it happens that a different rising edge of the signal triggers D3. This means that we could obtain different readings for the same distance, differing by around 20-25 microseconds, roughly the time period of the signal. So when we plot distance against time, we should consider only the linear region and discard these points.

50 readings of time were taken for each position of the receiver, and a plot of distance versus time was made. At some points, we have different values of time, differing by roughly the time period of the wave as predicted earlier. The longest straight section is taken, and fitted with the line

$$y = a_0 + a_1x \quad (3.1)$$

On performing the curve fit, we get

$$a_1 = 34.38$$

i.e. speed of sound, $v = 343.8\ m/s$

3.1.5 Result

The velocity of sound was measured to be $343.8\ m/s$, which is found to be in agreement with the accepted value of $343\ m/s$.

3.2 Reflection of Sound

We know the laws of reflection of light, but do they also apply to sound? Let us experiment and find out!

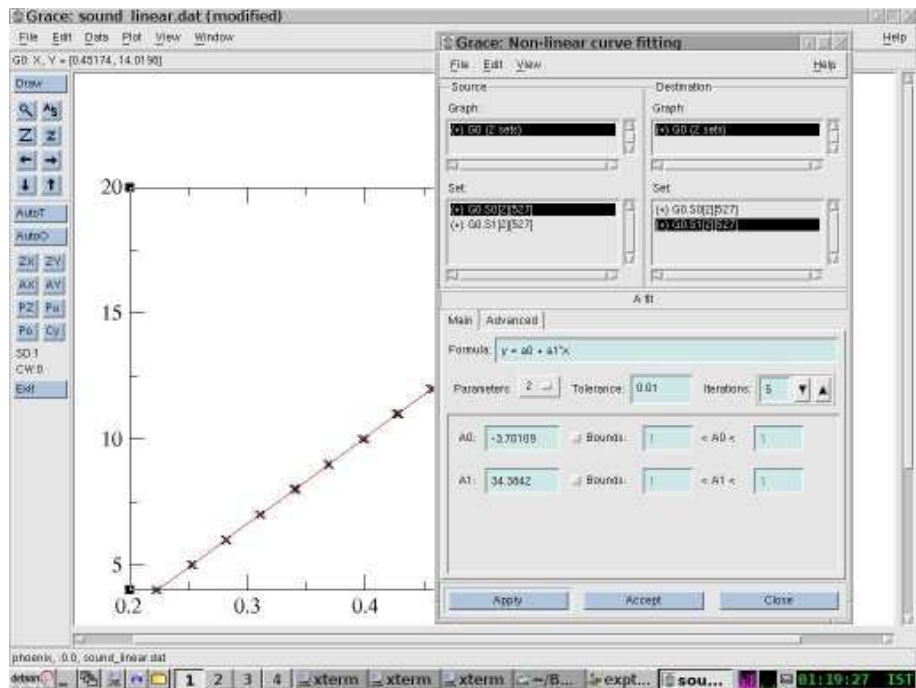


Figure 3.3: Fitting the linear portion

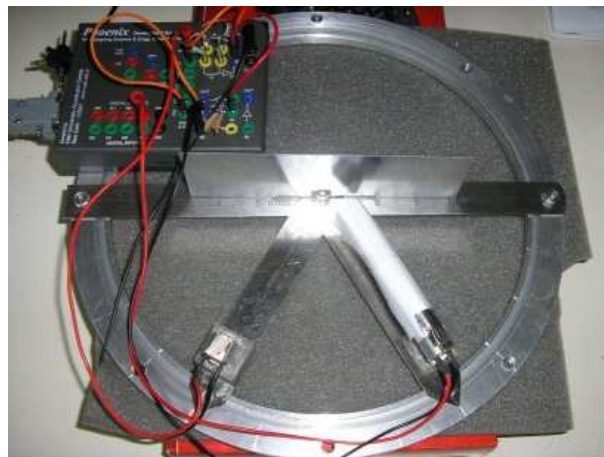


Figure 3.4:

- 3.2.1 Theory
- 3.2.2 Apparatus
- 3.2.3 Observations and Analysis
- 3.2.4 Results

Appendix A - Using XMGrace

Grace, which stands for "GRaphing, Advanced Computation and Exploration of data", is a 2D plotting tool for the X Window System. It is a powerful tool for analyzing data, and is licensed under the GNU General Public License. You can learn more about Grace from its website <http://plasma-gate.weizmann.ac.il/Grace/> . In the subsequent sections, we will see how we can do different kinds of data analyses using Grace.

Plotting Data

The data obtained from an experiment is saved in a file named, say *exp.dat*. Open a terminal and type `xmgrace exp.dat`. Grace expects the file to contain the points to be plotted, in the form of columns containing the x and y co-ordinates respectively. For example, let us assume that *exp.dat* contains the data shown in table 3.1. The plot of the data is shown in figure 3.5.

Curve Fitting

We use mathematical models for explaining various physical phenomena. These models usually have some arbitrary parameters which are particular to and contain information about the characteristics of the system being studied. For example, the discharging of a capacitor of capacitance C in series with a resistance R is described by the model

$$y = a_0 e^{-\frac{x}{a_1}} + a_2 \quad (3.2)$$

where a_0 , a_1 and a_2 are the parameters. These parameters can be interpreted as -

a_0 - initial voltage across the capacitor

a_1 - time constant RC

a_2 - offset

Now, suppose we have a set of values of voltage at different intervals of time. We can extract a lot of information from this data set by trying to 'fit' it onto the mathematical model given by eq by using software to adjust the parameters.

Histograms

Interpolation

x	y
1	10.234
2	4.233
3	3.135
4	2.653
5	2.245
6	1.84
7	1.342
8	1.001
9	0.843
10	0.65

Table 3.1: Data to be plotted

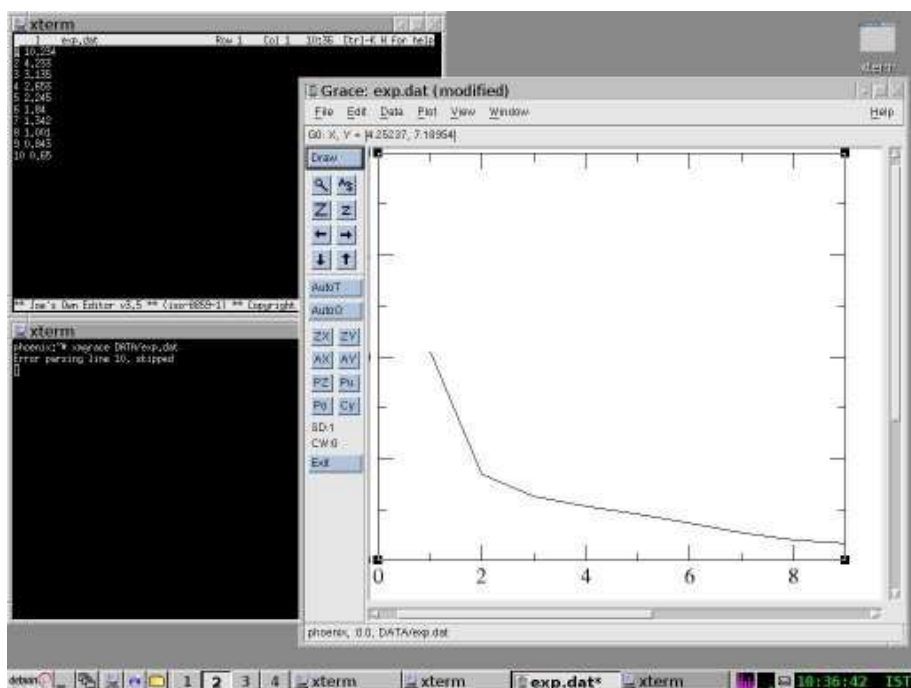


Figure 3.5: Plotting data using Grace