# PROJECT REPORT

By Akash Muni

Under Guidance of Prof. Rudrajyoti Palit.

Department of Atomic and Nuclear Physics

In Co-ordination with,

Mr. Farhan S. Babra.

Mr. Nitin Kamble

Mr. Sheetal Kumar Jadhav.

Tata Institute of Fundamental Research, Colaba , Mumbai

# Lifetime Measurements of nuclear states using Recoil Distance method(RDM) : Making of thin metal foils and testing of Piezoelectric Actuator

## Lifetime measurements of nuclides using Recoil-Distance method.

# Introduction :

Nuclear properties of excited elements are studied by inducing nuclear reactions. One such nuclear property is nuclear structure, which can determined by using the lifetime of the excited nuclei lives on a certain energy level which will eventually then decay to different others levels releasing some energy before achieving stability. These isomers (excited states of the same nuclei) release energy in the form of gamma rays having different energies. The gamma rays given out are then detected on certain detectors placed on different angles surrounding the target [3]. There are different types of detectors used according to the requirement. In our case we have HPGe detectors in array with scintillator detectors. These detectors then collect the gamma rays which give a pulse rise in them which are then fed to a data acquisition system giving out a spectrum which is further studied to find lifetime of isomers.

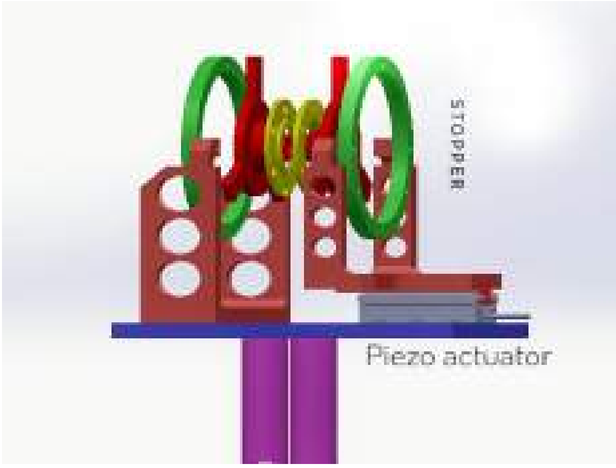
There are different methods of measurements of lifetime namely

1. Pulsed Beam Method
2. Doppler shift Attenuation Method
3. Recoil-Distance method (RDM)

Using RDM, lifetime of nuclides in the range of few pico seconds($10^{-12}$) to few nano seconds($10^{-9}$) can be measured [1]. Since RDM method has such range it can be used to study short lived nuclei. The RDM has a very simple setup which includes a plunger. The plunger setup is shown beside -

The basic components in the plunger setup are

1. The Target
2. The stopper
3. Movable piezoelectric motor/actuator
4. Detachable target and stopper holder



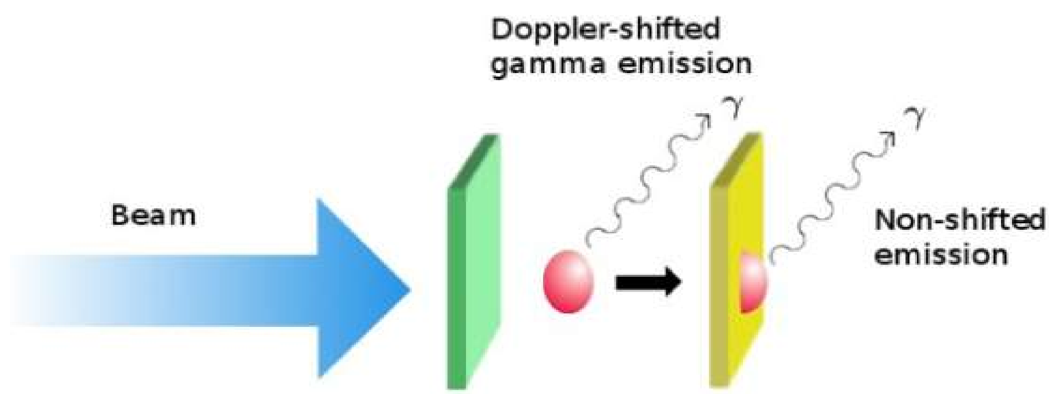

*Plunger*

**Working :**

The desired target is mounted on the holder and the desired stopper is mounted on to another holder. Both these detachable holders are then attached on to the plunger setup. Note that the stopper is mounted on to the movable piezoelectric actuator. This is then placed where the target will meet the highly accelerated beam.

The guided beam first hits the target populating excited nuclei. These recoil nuclides then come to ground state by releasing energy in the form of gamma rays which are Doppler-shifted and are then stopped in the stopper foil. The distance between the stopper and target foil can be adjusted so that the nuclei comes to rest in the stopper at different distances according to their corresponding excited energies. Many of the times the nuclei releases energy even after entering the target foil these are the non-shifted emitted gamma rays, for this reason the stopper needs to be of thickness more than the target foil and proper element must be chosen so that the nuclei does not leave the stopper foil. The energy released in the form of gamma rays are then detected on the detectors placed at different angles.

Let us now see how are these target and stopper foils prepared using different methods.




*RDM Principle*

# Preparation of thin metal foils.

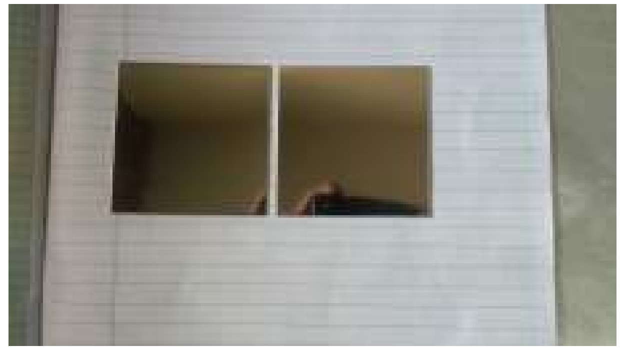
## Overview :

In any nuclear physics experiment the basic requirement or need is making of certain targets on which the highly accelerated particles will be bombarded on to populate excited nuclei. Targets used in nuclear research in most cases are made of the enriched isotopes. They have various dimensions, thickness, physical (solid, liquid, gaseous) and chemical (elemental, compound or alloys) forms. They can be self-supporting or on a backing, they can be used inside the accelerator (so called internal targets), or in external setups on the beam lines. For certain experiments the target is directly made on the backing(works as stopper) but in RDM we use a stopper foil which is mounted and can we moved by finite distances. The foils should be of areal density in the range from 100ug/cm2 to 15mg/cm2. Apart from these the uniformity of density, proper size, impurities should be taken care off while preparing the foils. The method production of foils depends on various factors such as the chemical and physical properties of the material used. Metals having high malleability and ductility are easy to prepare using simple rolling technique, while metals that are softer are bit difficult to prepare. Also some material are in either powder form or are reactive to air therefore a method much more complicated than rolling needs to be applied. Both the target and stopper foils can be prepared by using the following methods :-

1. Rolling under pressure/ Cold rolling
2. HIVIPP (High energy Vibrational Powder Plating)
3. Vapor condensation at which the deposited material can be heated by resistant heating.
4. Electron bombardment,  electron beam gun
5. Levitation heating and melting
6. Electro-deposition

Out of all these methods most simple method is rolling under pressure which I learned. The basic process of rolling is very simple and easy to learn. The picture of the roller is given. fig 1.3

*Hard Roller (fig1.3)*



*Mirror Finished SS plates (fig1.4)*

The principal of rolling is easy and is the most cost-effective method of preparing target foils of thickness between 100ug/cm$^2$ to 15mg/cm$^2$. In this method the material is placed between two mirror finished SS-304 plates(shown fig 1.4) and then inserted in the roller. The roller presses the plates gradually increasing the area of the plates as well as the material kept inside [2].

This process is repeated again and again until desired areal density is achieved. Most metal targets are made using this technique as they are malleable. Before each roll the foil is kept in different locations on plate since keeping them on the same place will create breaks and cracks due to the depth created by the foil in the previous roll. Not just this but also maintaining the cleanliness of the SS plates is also utmost important as small dust particles could damage the final metal foil. For this purpose use of Alcohol is found to be the most reliable. Rubbing the surfaces of the plates with alcohol using a lint free tissue paper helps in keeping the foil/plates clean throughout the process. Another most important aspect is keeping the foil in good shape and maintaining the flatness without any cracks. Also to prevent sticking applying alcohol helps a lot.

**Preparation of Aluminum Foil of thickness ~550ug/cm$^2$ :**

A thick Aluminum foil of thickness 6.5mg/cm$^2$ was first taken. The edges of the foil was first trimmed off and then was cleaned thoroughly by dipping the foil in alcohol. Then the foil was placed properly on the mirror finished side at a corner of the SS plate. Another plate was kept over the foil , this was then carefully placed under the hard cylindrical roller. After certain consecutive rolls the foil becomes thin having areal density below 1.5mg/cm$^2$. Since the foil has now become extremely thin its starts sticking to the plates. To prevent sticking the foil is dipped in alcohol and then placed on this plate. A desired thickness of below 600ug/cm$^2$ was achieved. Since Al has low density this kind of lower thickness was achievable. The following procedure was done to measure the thickness

1. The foil was first carefully removed from the plate then was weighed on a microbalance scale.
2. The area of the foil was measured by using a graph paper.
3. Ratio between weight and area, gives the final thickness of the foil
4. The area was found to be approximately

After the foil was prepared it was properly cleaned and the surface was made flat and then properly placed in butter paper for further use.

*Aluminum ~660mg/cm2(fig1.5)*

*Aluminum 560mg/cm2(fig 1.6)*

**Preparation of Silver foil of thickness ~1.233mg/cm$^2$ :**

Unlike Aluminum, Silver has high density and is a soft metal. A thick foil was first taken which was then rolled a few times to bring the thickness down to 3mg/cm$^2$ . By this time the foil was thin enough to stick to the plates. To avoid sticking again alcohol was used . The first foil prepared without alcohol and proper cleaning of plates had a few pinholes in them. Therefore while preparation of the next foil utmost care and proper cleaning of plates were ensured. The foil without pinholes are displayed below. fig1.7

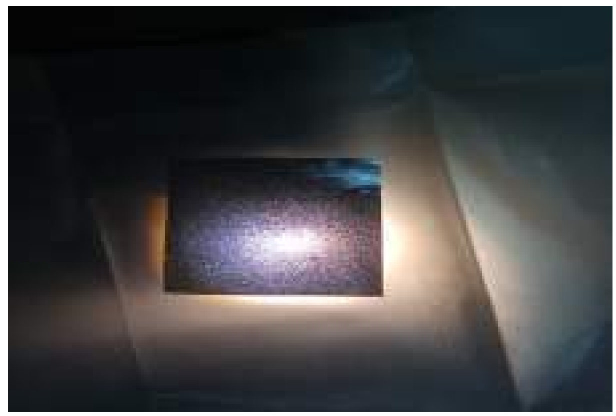
Proper single roll was used instead of back rolling to save the foil from tearing. A final thickness of 1.233mg/cm$^2$ was achieved. Since further rolling of foil could increase the number of pinholes and could tear the foil it was stopped at 1.23mg/cm$^2$ . Also an irregular foil of thickness ~800ug/cm$^2$ was prepared during this course. was properly cleaned and the surface was made flat and then properly placed in butter paper for further use.

*Silver 1.233mg/cm2 (fig1.7)*

**Preparation of Tantalum foils of thickness 7mg/cm$^2$ :**

Silver and aluminum both will be used as target foils but tantalum being an hard metal and most non reactive it will be used as a stopper. For the preparation of tantalum natural occurring tantalum was taken. The first step is same as preparing silver and aluminum. 62 mg/cm$^2$ of tantalum was taken which was cut in proper size and the unwanted edges were trimmed off. This thick foil was then rolled similarly as before placing it in SS plates. Here the pressure steps were much more stronger than used before, since it is a hard metal and takes much more pressure to roll than aluminum and silver. During rolling tantalum, alcohol was not used at all as using alcohol develops pinholes and makes the final foil looks like net even at higher thicknesses.

*Without Alcohol (7mg/cm$^2$)*

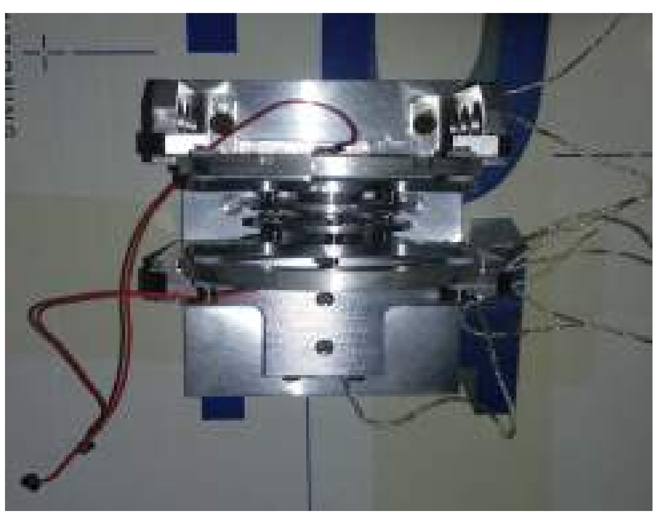


*Alcohol used (13mg/cm$^2$)*

There are pictures of two foils displayed above one was rolled using alcohol and the other without using alcohol. It is clearly visible that the one in which alcohol was used develops a net like structure and cannot be used as a stopper.

Final result was two foils of thickness ~7mg/cm$^2$ and ~10mg/cm$^2$. Area of both the foils were sufficient.

These prepared foils will be used as target and stopper in the plunger setup shown below.



## Measurement of thickness of foil using Alpha source

One method which is generally used in measuring the thickness is by weighing the foil on a microbalance scale and then finding its area using a graph paper. The ratio between the weight and the area will give us the final thickness. Since this method has a lots of errors such as

1. while weighing the microbalance scale was not tared properly
2. if the area of the foil is irregular it becomes difficult to take an estimate,

it is not reliable to get the thickness using this method if our experiment demands accurate results. Therefore an method which is more accurate and will give results without errors needs to used.

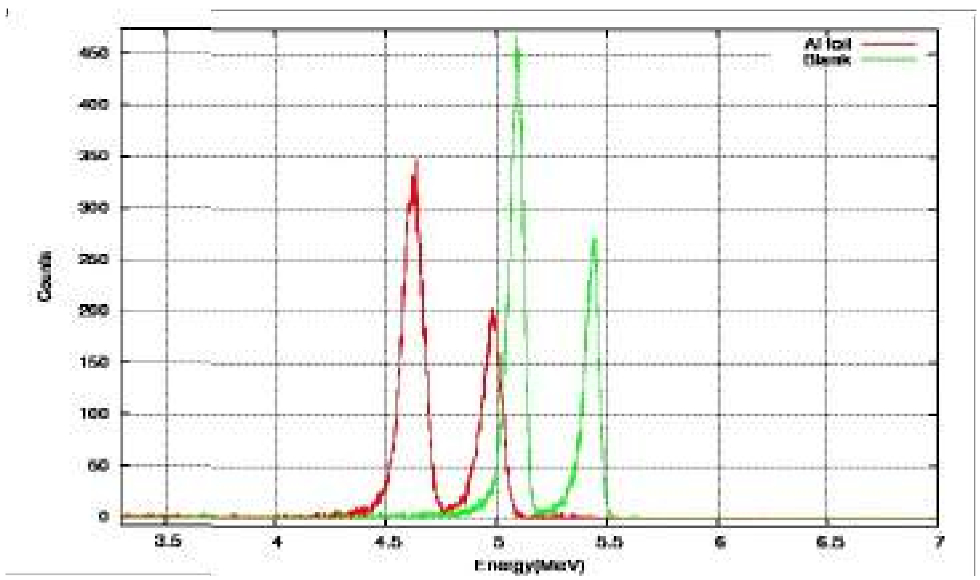
Methods based on charged particles energy loss could be used to measure the thickness of the foil [4,5]. Here we have a setup which has elements who emit alpha particles and could be detected easily on a detector.

**Setup :**


The picture of the setup is shown above. It consists of a vacuum chamber. Inside the chamber at one end there is a alpha source and exactly to the opposite end of source there is a detector. The foils can be mounted on a retractable rod which will then be pushed in between the source and the detector. The source is a mixture of americium and plutonium while the detector is silicon surface barrier detector. The chamber needs to be in vacuum for the measurement to take place since alphas lose energy even while traveling through air. Vacuum is attained by pumping the air out using a rotary and diffusion pump.

**Experiment :**

The required foil is first mounted on the rod properly then it is placed properly in the chamber. First the chamber is bought into vacuum, once the desired vacuum is achieved then the detector is given bias. Only blank readings are taken first without bringing the foil in between. An spectrum is recorded on a computer using proper electronics and software's. The the foil is pushed between the source and detector, as alpha particles are heavier they lose energy while passing through the metal foils. These new alphas give rise to another spectrum which has less energy than the blank spectrum.
The shift in peak and energy in the spectrum is displayed below.




Above shifted red spectrum is when alpha particles pass through Aluminium foil.
The required values needed to calculate thickness is displayed below in the table

| $E_\alpha$<br>MeV | E'(After passing through Aluminium)<br>MeV | $\Delta E$<br>MeV | dE/dx<br>(stopping power)<br>KeV | Thickness<br>$mg/cm^2$ |
|---|---|---|---|---|
| Americium-5.485 | 4.983 | 0.505 | 0.5698 | 879 $ug/cm^2$ |

Since the thickness matches the manual measurement which is 800 $ug/cm^2$ the found thickness is even more accurate.

## Distance measurement using capacitance induced between foils.

### Introduction :

The next importance thing is moving the stopper at finite distances from the target for our experiment. For this purpose we have a piezoelectric actuator in our plunger setup. We need to study the movement of the piezoelectric actuator using capacitance method. This motor/actuator is controlled via a controller which is connected to computer and is operated by a software which is specially designed for this purpose.

**► PIEZOELECTRIC ACTUATOR :**

The piezoelectric actuator is a piezoelectric crystal which operates on a inverse piezoelectric principle.

When an mechanical pressure or force is applied on a piezoelectric crystal is gives out a voltage. In an opposite case when a controlled voltage is applied to the piezo crystal it expands , this is known as inverse piezoelectric effect.

There are different kinds of piezoelectric actuators , out of all the different kinds one that we have is a Inertia type (Stick-Slip action). The crystals are usually made of piezoelectric ceramic disks. Most of the piezoelectric crystals are made up of PZT (Lead Zirconium Titanate) and Barium Titanate [6]. Both of these materials have the property of typical piezo quartz crystal. In inertia kind of actuator the expansion is rapid and is in steps. The velocity depends upon the applied frequency and the distance traveled by it is in micrometers. The basic requirement for such an sophisticated actuator is because we need a high precision movement in our experiment. The direction of applied voltage and frequency decides which side will the crystal expand and contract and what will be its velocity. An image of the actuator is given below:-

One experiment which will tell us the movement of the motor is using capacitance measurement when the foils are on the plunger setup and when an controlled voltage is applied on the foils. Using the data collected we could find the average distance traveled by the motor when a particular number of steps is given. The controller helps in supplying the motor the correct amount of parameters given.

**Experimental setup** :

The experimental setup is shown in picture below.

Two thin aluminum foils (thickness ~1mg/cm$^2$ and ~700mg/cm$^2$) were first prepared using the rolling method. These were then stuck on the holder using super glue. Then the foil is stretched to remove wrinkles and to make the surface as flat as possible. Once this is done then the holders are properly mounted on the motor setup without disturbing the surfaces. A prefect parallel alignment is required between the holders for our experiment.
After this is done then motor and the controller are connected to a power supply. The controller is connected to a computer using a usb cable supplied by the manufacturer which is specifically designed for the plunger setup.
A circuit was designed which will help us give our readings. The circuit is simple RC circuit which is shown below containing two resistors of 10MΩ each in series and a capacitor of 0.1µf. This circuit just helps in charging and discharging of capacitor. A certain amount of voltage is supplied on the foils through the circuit(1V) , then the corresponding output is fed on to a oscilloscope which is used to get the results.

**Precautions taken before starting the Expt. :**

1. All the equipment's were properly tested for faults and proper functioning.
2. Circuit was properly tested before connecting to the the motor setup.
3. Before beginning the experiment the manual and data sheet of the controller and the motor was properly studied.
4. Proper grounding and insulation was ensured.
5. Proper physical conditions were maintained throughout the experiment.

**Pre-Experiment Results/ Calculations :**

Before beginning the experiment some theoretical results were taken assuming ideal conditions which will later be matched with the experimental results.

The basic idea behind the theoretical data is using the available formulas to calculate capacitance. To calculate we knew the area of the surfaces and the dielectric between the plates. Capacitance is basically collection of charges between two surfaces. These surface are conductors and the material between them is usually an insulator.

The capacitance's between the surfaces were calculated using the formula

$$C = \varepsilon A / d$$

here,

$\varepsilon$ = permittivity of vacuum= $8.854 \times 10^{-12}$

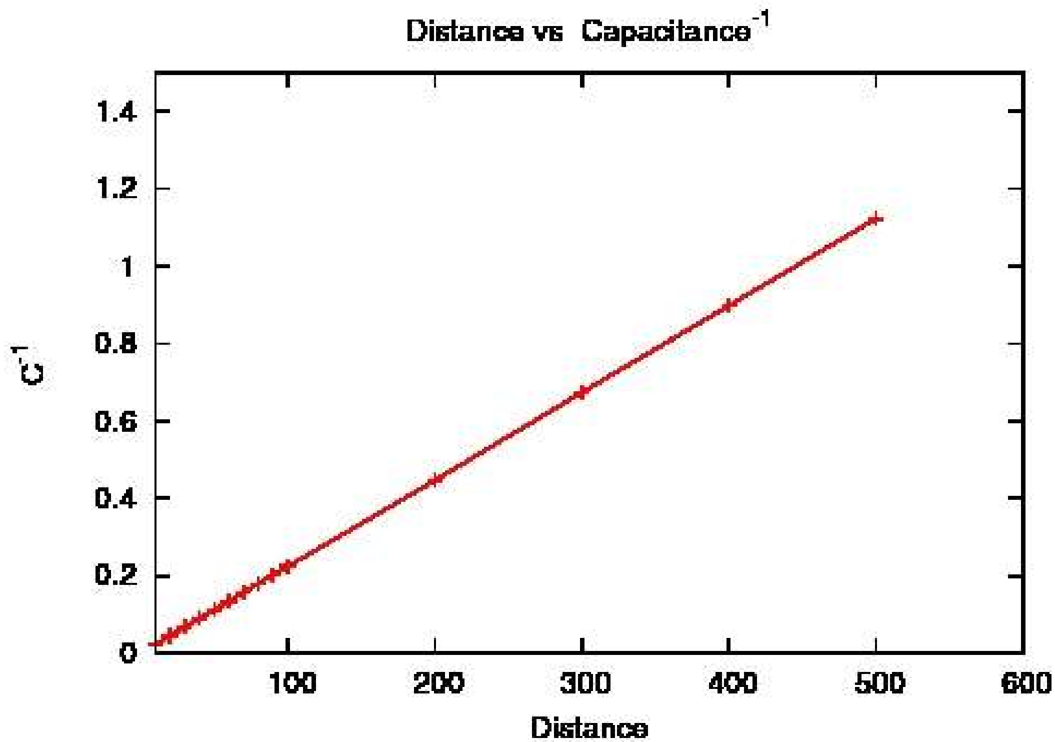
A = Area of the surface = $50.272 mm^2$

d = distance between the surfaces

Since area and dielectric value is constant we assumed distances in micrometers in a interval of 10 um. All the data calculated and assumptions as listed below in the table.

| Distance(um) | Capacitance(pf) | Distance(um) | Capacitance(pf) |
|---|---|---|---|
| 10 | 44.5221619 | 90 | 4.9469068 |
| 20 | 22.261081 | 100 | 4.45221619 |
| 30 | 14.8407206 | 200 | 2.2261081 |
| 40 | 11.1305405 | 300 | 1.48407206 |
| 50 | 8.90443238 | 400 | 1.11305405 |
| 60 | 7.42036032 | 500 | 0.890443238 |
| 70 | 6.36030884 | | |
| 80 | 5.5652704 | | |

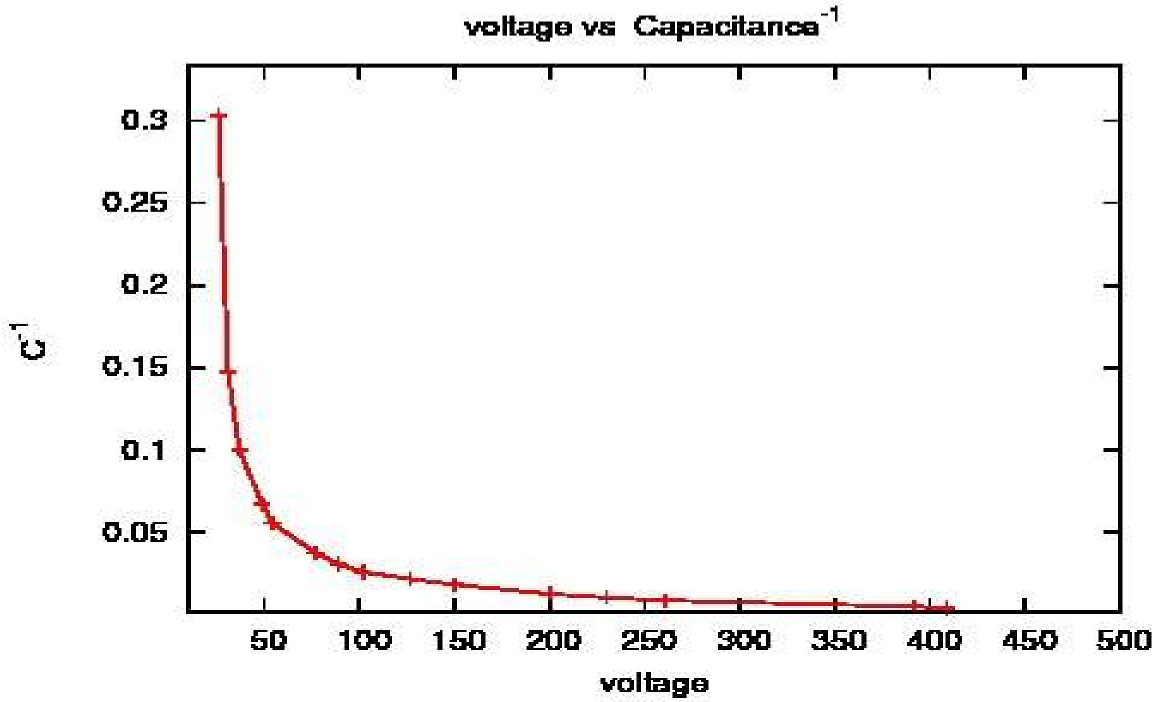
A graph of d vs $C^{-1}$ was plot. The graph is displayed below.




One component in our circuit is the capacitor which is the two thin foils. Instead of the foils we used known capacitors to find out the output voltage given by them. This will then be used to compare it with the capacitance induced by thin foils at a certain distance between them. The output voltage is noted for capacitors in the range of pico farads using a oscilloscope. An input pulse(sin wave) from a pulse generator was fed to one end of capacitor and the output from other end was taken. The voltages given by the known capacitors is given in table below

| C(pf) | Output Voltage(mV) | C(pf) | Output Voltage(mV) |
|---|---|---|---|
| 3.3 | 26 | 56 | 150 |
| 6.8 | 31 | 82 | 200 |
| 10 | 37 | 100 | 230 |
| 15 | 49 | 120 | 260.5 |
| 18 | 54.3 | 220 | 392 |
| 27 | 77 | 270 | 408.75 |
| 33 | 89 | | |
| 39 | 102 | | |
| 47 | 126.75 | | |

A graph of Voltage vs $C^{-1}$ was plot. Shown below




The last theoretical measurement was solving the circuit to get equations in forms of certain variables(voltage, capacitance,resistance)
Using simple khirchoff's law and other electrical formula based for capacitance and impedance the circuit was solved. The final equation is which gives output voltage when a particular value of capacitance is substituted in it was solved using a mathematical software called mathematica since the equations had complex variables in it.
The results are displayed below

| C(pf) | Output Voltage(mV) | C(pf) | Output Voltage(mV) |
|---|---|---|---|
| 3.3 | 25 | 56 | 155.5 |
| 6.8 | 30.3 | 82 | 214.5 |
| 10 | 37 | 100 | 249 |
| 15 | 49 | 120 | 283 |
| 18 | 56.7 | 220 | 386 |
| 27 | 80 | 270 | 412 |
| 33 | 97 | | |
| 39 | 112 | | |
| 47 | 133 | | |

To verify whether the mathematical software and the calculations done are correct a circuit simulator was used. The same circuit was plot onto it and given the correct parameters and output was recorded. It was found that results obtained using simulator and mathematica and using real capacitors are almost equal.

Therefore using capacitance measurement one can find out distance.

## Conclusion :

During the course, foils of different metals were prepared with different areal density which will further be used in recoil distance method of time measurement.
An aluminum foil of thickness 560 mg/cm$^2$ , sliver 800mg/cm$^2$ and tantalum 7mg/cm$^2$ was prepared. Thickness measurement of foils using alpha source was done which gave accurate and corrected thicknesses of the prepared foils. Also the testing of piezoelectric actuator was done in which capacitance measurement was used to find out the distance traveled by the actuator. Different simulation software were also used to compare the results obtained.

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