جامعة الملك فهد للبترول والمعادن

King Fahd University of Petroleum & Minerals

# PHYS 403

## Lab Report

Experiment# 4

# Nuclear Magnetic Resonance

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**Objective:**

- To determine the spin-lattice relaxation time (T1) for light mineral oil
- To determine the spin-spin relaxation time (T2) for light mineral oil

**Introduction:**

Nuclear magnetic resonance (NMR) works essentially on the same principle as electron spin resonance (ESR) (c.f. ESR report), albeit with the nuclear spin for the former. NMR applications are growing in the fields of physics, chemistry and biology.

For the nuclear spin, a new quantum number, the spin angular momentum (I) is introduced; also the magnetic quantum number $m_i$ is quantized as

$$m_i = I, I-1, I-2, \ldots, -I$$

For the proton, I = 1/2, and therefore, $m_i = \pm 1/2$. Accordingly, the proton has two degenerate states in the absence of an external magnetic field. The magnetic moment of the spinning proton can be affected by an external magnetic field:

$$U = -\mu . B \ldots (1)$$

This external magnetic field breaks the degeneracy of the system and splits the energy levels to two states with energy difference given by:

$$\Delta E = \gamma m_{1/2} \hbar B_0 - \gamma m_{-1/2} \hbar B_0 = \gamma \hbar B_0 \ldots (2)$$

Due to the uncertainty principle, only the z-component of the spin is a sharp number, whereas the components in the x and y directions are fuzzy. They precess with the Larmor frequency given by:

$$\omega = \gamma B_0 \ldots (3)$$

When the proton absorbs light with corresponding resonance frequency given by:

$$\Delta E = hf = \gamma \hbar B_0 \ldots (4),$$

it is excited from the ground spin state to the excited spin state.

Figure 1 depicts these effects.

When a magnetic field is present, magnetization occurs; the net magnetization in along the z-axis is given by:

$$M_z = \frac{1}{2} \gamma \hbar \Delta N \ldots (5)$$

where ΔN is the difference in the number of protons in the two spin states. At equilibrium, the populations are given by Bolzmann's distribution

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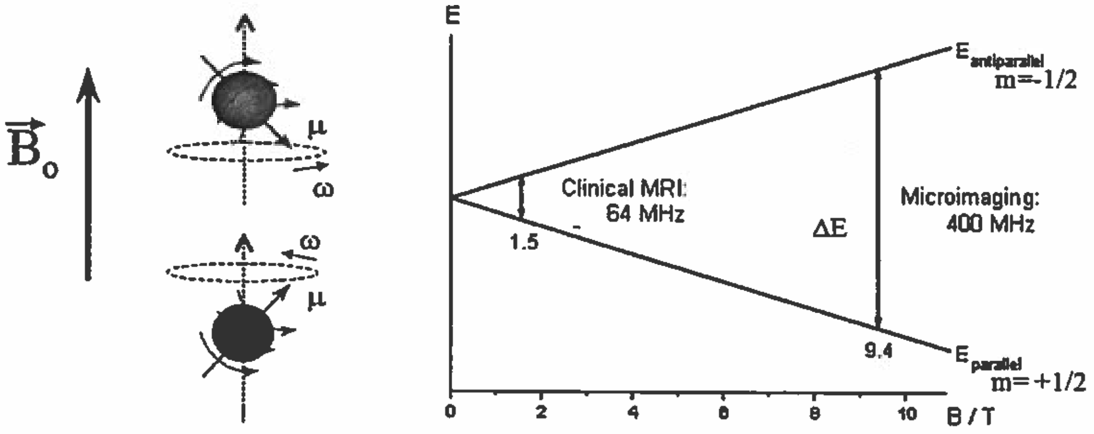



**Figure 1:** (left) Representation of the spin procession about an applied magnetic field at the Larmor frequency. (right) Energy level splitting of a proton that is either aligned with the magnetic field or antiparallel to the field.

$$\frac{N_+}{N_-} = \exp\left(\frac{\gamma\hbar B_0}{kT}\right) \ldots (6)$$

The resonance photons disturb this equilibrium. The system tends to return to the equilibrium state, or relax. This occurs through two processes spin-lattice relaxation and spin-spin relaxation with corresponding relaxation times, $T_1$ and $T_2$, respectively.

The spin-lattice relaxation time refers to the mean time ($T_1$) for a nucleus to return back to its thermal equilibrium state in its surroundings (the lattice) after it has been exposed to an RF signal (pulse).

On the other hand, once the nuclear spin population is relaxed to equilibrium conditions in the magnetic field, it can be probed again. Precessing nuclei can also fall out of alignment with each other (returning the net magnetization vector to a non-precessing field) and stop producing a signal. This is called spin-spin or transverse relaxation and the time required for this process to occur is referred to as $T_2$.

**Determination of $T_1$**

A two pulse inversion-recovery sequence can be used to determine $T_1$. The pulse sequence is:

$$180^0\text{---}\tau\text{---}90^0 \text{ FID}$$

The first pulse ($180^0$) inverts the z-component of the magnetization from Mz to –Mz, but the spectrometer cannot detect magnetization along the z-axis. It only measures net magnetization in the x-y plane. So a second pulse ($90^0$) is used to rotate the net z-component of the magnetization into the x-y plane where the magnetization can produce a measurable signal $M_y(\tau)$ or $M_x(\tau)$. A series of $M(\tau)$ values can be obtained by varying the delay time ($\tau$) in between the pulses. The recovery is an exponential process and is observed when we plot $M(\tau)$ versus $\tau$. From the curve, we can measure Meq, (the thermal equilibrium magnetization). The quantitative expression of this process is:

why exponential ?

$$\ln\left(\frac{M_{eq} - M(\tau)}{2M_{eq}}\right) = -\frac{\tau}{T} \dots (7)$$

A plot of the ln((Meq-M(τ))/2Meq ) versus τ reveals a linear graph. The slope of this graph is equal to $-1/T_1$.

**Determination of $T_2$**

A two-pulse spin echo sequence can be used to determine $T_2$. The pulse sequence is:
$90^{\circ}$--- τ ---$180^{\circ}$ --- τ --- echo (2τ)
The first pulse ($90^{\circ}$) is used to rotate the thermal equilibrium magnetization ($M_{eq}$) from the *z*-axis to the y-axis followed by the short interpulse time delay τ. The second pulse ($180^{\circ}$) flips the magnetization across the x-y plane. After the $180^{\circ}$pulse, the spins in the higher field ($\omega_f$) get out of phase and precess faster than $\omega_0$, but at 2τ they return to the in-phase condition. The slower precessing spins ($\omega_s$) at the lower field get out of phase and rephase again after a time 2τ. The net magnetization in the *x-y* plane is decreasing and will finally decay to zero. This rephasing of the spins generates a spin-echo signal that can be used to measure $T_2$. The net *x-y* magnetization as measured by the maximum echo is written as:

$$\ln\left(M_{x,y}(2\tau)\right) = -\frac{2\tau}{T_2} + \ln\left(M_{eq}\right) \dots (8)$$

A linear curve with a slope of ($-1/T2$) is obtained as we plot $\ln(M_{x,y}(2\tau))$ versus 2τ. So $T_2$ can be calculated from the slope.

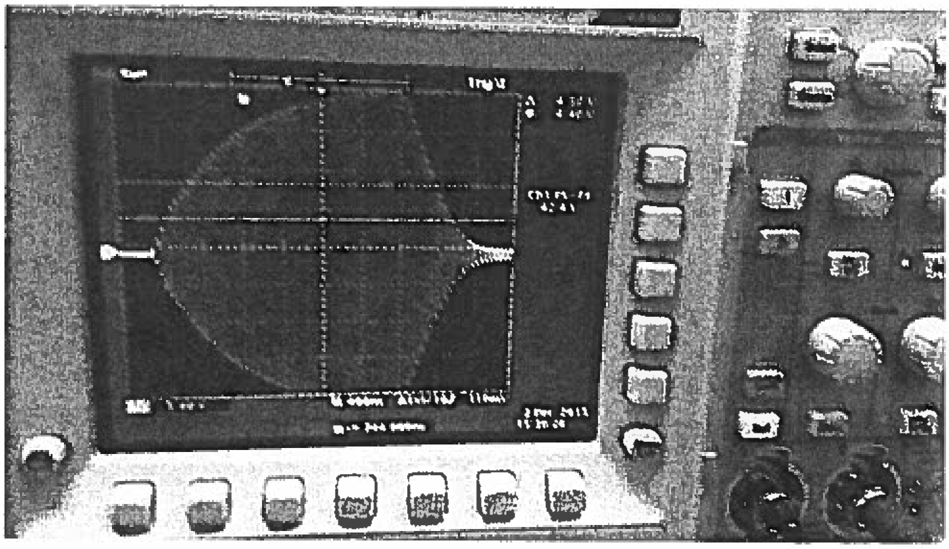
This is method explain physics.

**Procedure:**

Refer to lab manuals.

**Data Analysis and Discussion:**

The signal was maximized as shown in the figure:



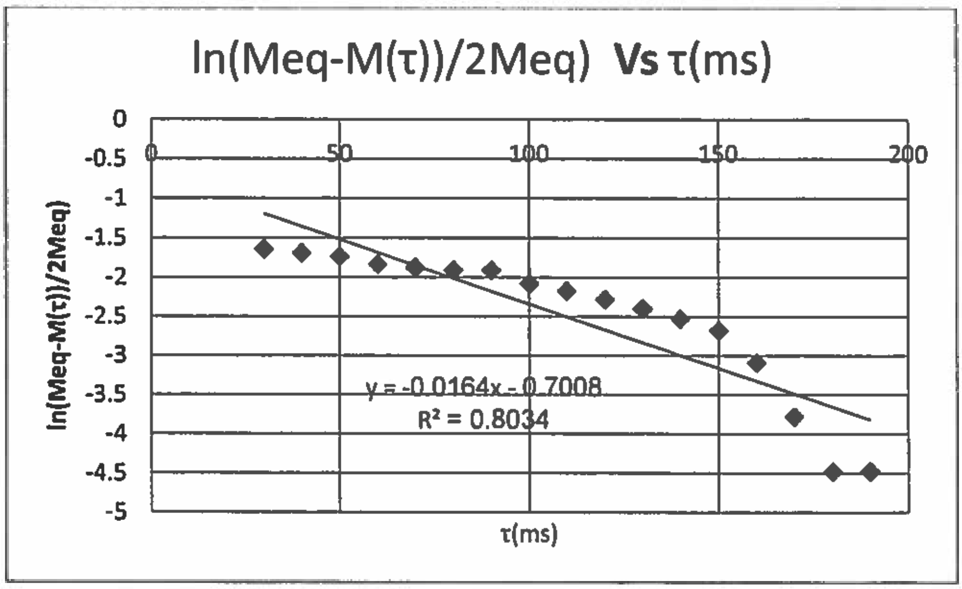
caption?

**Determination of $T_1$:**

| Table 1 Experimental Parameters | | |
|---|---|---|
| F (MHz) | $90^0$ | $180^0$ |
| 20.974 | 5.98 | 12.1 |

| Table 2 Experimental results | | | |
|---|---|---|---|
| τ(ms) | M(τ) (V) | (Meq-M(τ))/2Meq | ln(Meq-M(τ))/2Meq) |
| 30 | 5.4 | 0.193182 | -1.64412 |
| 40 | 5.56 | 0.184091 | -1.69233 |
| 50 | 5.72 | 0.175 | -1.74297 |
| 60 | 6 | 0.159091 | -1.83828 |
| 70 | 6.1 | 0.153409 | -1.87465 |
| 80 | 6.2 | 0.147727 | -1.91239 |
| 90 | 6.2 | 0.147727 | -1.91239 |
| 100 | 6.6 | 0.125 | -2.07944 |
| 110 | 6.8 | 0.113636 | -2.17475 |
| 120 | 7 | 0.102273 | -2.28011 |
| 130 | 7.2 | 0.090909 | -2.3979 |
| 140 | 7.4 | 0.079545 | -2.53143 |
| 150 | 7.6 | 0.068182 | -2.68558 |
| 160 | 8 | 0.045455 | -3.09104 |
| 170 | 8.4 | 0.022727 | -3.78419 |
| 180 | 8.6 | 0.011364 | -4.47734 |
| 190 | 8.6 | 0.011364 | -4.47734 |
| 200 | 8.8 | 0 | #NUM! |

Caption




caption

Page #

From the slope, $T_1$ for the light mineral oil can be determined from equation (7) as 60.97 ms, with Meq = 8.8 V.

**Determination of $T_2$:**

Determination of $T_2$ is challenging. In fact, the instrument probably has some defects in that the magnetic field cannot be controlled by the magnetic field gradients. More importantly, the instrument was not showing any response to the presence of the sample and the Gaussian-like peak did not appear at all, not to mention the change of the magnetization potential with the variation of $\tau$. Therefore, I failed to complete this part of the experiment.

**Conclusion:**

This experiment was designed to investigate the basic NMR phenomenon and to determine the values of the spin-lattice relaxation and spin-spin relaxation times. The instruments is apparently not in good condition. The determination of $T_1$ was achieved with difficulties whereas determining $T_2$ was not successful. This experiment may require improvement.

**References:**

Lab manuals.

# Optical Pumping of Rubidium

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## Abstract

This report explain a part of history and a mixer of physics in deferent field to show to the people and scientist that physics is an effective subject in all field and it is developed on the time and not just die. This paper put you on the picture to be know what is OP and how to deal with it followed by the experiment where it have a good explanation and result. Finally, the conclusion will be outlined.

25October 2015

## Table of Contents

## INTRODUCTION

Using the light photons to change the population and redistribute the set of energy levels of a system from the Boltzmann distribution a system of atomic spin orientations is "pumped" from an equilibrium distribution over magnetic sub-states into a non-equilibrium distribution in which a large majority of spins are aligned in a given direction that is "Optical Pumping".

Optical pumping first introduce by the French physicist whose award Nobel Prize he is Alfred Kastler. That was in 1950 and he was awarded the Nobel Prize in 1966 "for the discovery and development of optical method for studying hertzian resonance in atoms".

In this report I'll record all what I have been faced in the experiment and I'll noted that by a problem with its observation and try to explain it with its solution that I have decide.

## BACKGROUND

In this experiment we will use the most sensitive dives I have ever deal with. So, some problems I faced in this experiment will appear in this paper so don't be upset about it and I'll try to explain how I cross it.

Also, in this experiment we will use atomic physics and some part of optics physics but I'll explain all what regarding the experiment we done and I'll neglect what make you confused.

Finally, Optical Pumping is very important machine that allow you studding the collision and effective of temperature and density in the process. Although this experiment quit old but it have a current topics.

# Theory

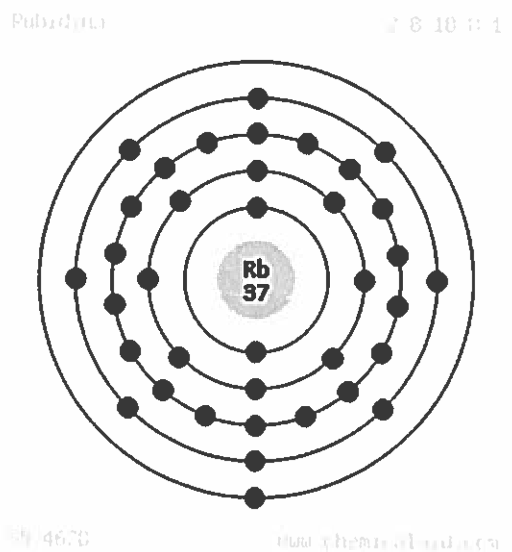
## Alkali Atoms

Alkali metals are a group one in the periodic table consisting of the chemical elements (Li), (Na), (K) rubidium (Rb), (Cs) and francium (Fr). This group lies in the s-block of the periodic table of elements as all alkali metals have their outermost electron in an s-orbital: this element/electron configuration results in their characteristic properties. The alkali metal behaved as a hydrogen atom in the structure.

Rubidium (Rb) is the alkali metals that we will use in this experiment. Its atomic $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 5s^1$

Or: $[Kr]\ 5s^1$

And to be easy her is a diagram shows the Rb atom with energy shells as it in a stable form.



## You can ask why we chose Rb?

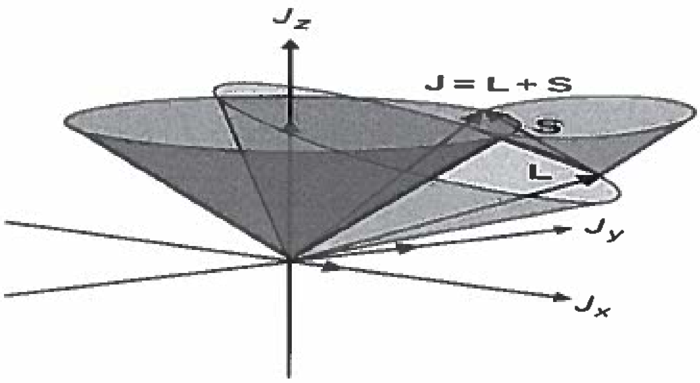
The simple answer to this question is because of its hydrogen-like qualities in having one atom in the outer shell and its ability to share this atom much faster and also its isotopes that is $_{87}$Rb. *Not right completely. It has L and I* *only partially right*

Now I have to introduce some quantum quantity to describe the outer shell:

| symbol | what is means |
|---|---|
| L | orbital angular momentum |
| S | spin angular momentum |
| J | total angular momentum |
| $\mu_S$ | magnetic dipole moment of S |
| $\mu_L$ | magnetic dipole moment of L |

And from the above table we can see that the total angular momentum is:

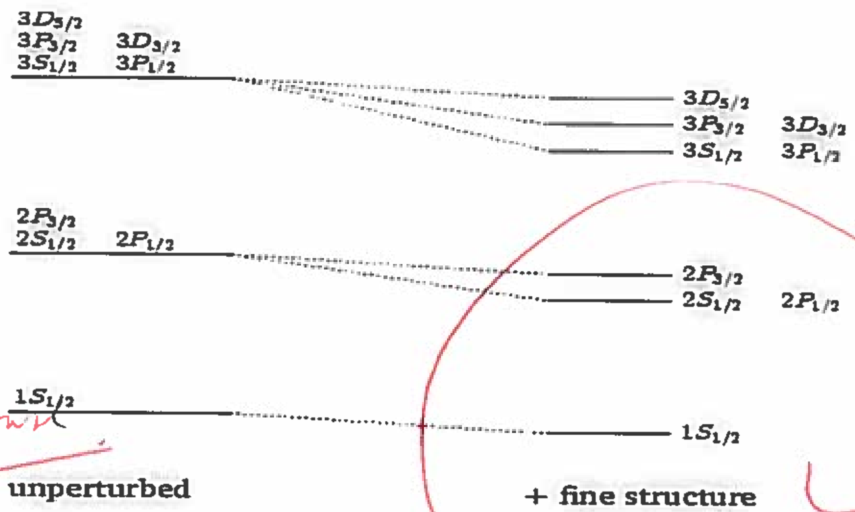
$$J=S+L$$



## Fine and Hyperfine Structure

In the spectroscopic notation the electron state is $^{2S+1}L_J$. So the ground stat of alkali atoms is $^2S_{1/2}$ with a first exited stat with L=ħ and it is designated as a P state. In this P stat J can have the two values just L+S and L-S. Then the two states are $^2P_{1/2}$ and $^2P_{3/2}$. And these states have deferent energy which split in specific way and that is known by Fine structure.

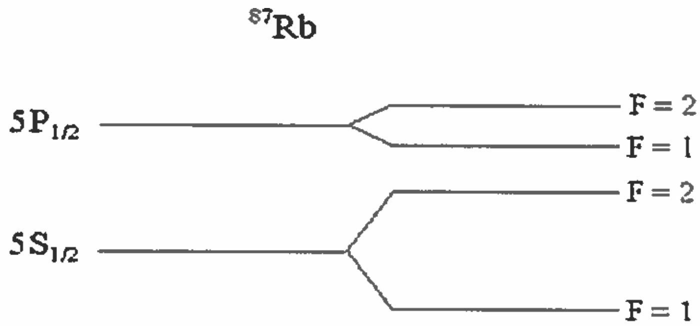
This is not the right picture




The nuclear spin coms to the picture and it is written I. And know we must include it in account and that cussed what we call Hyper Fine Structure (HFS) and its can be written in Hamiltonian notation as:

$$H = ha\, I.J$$

?




## How Magnetic Field Affect the Alkali?

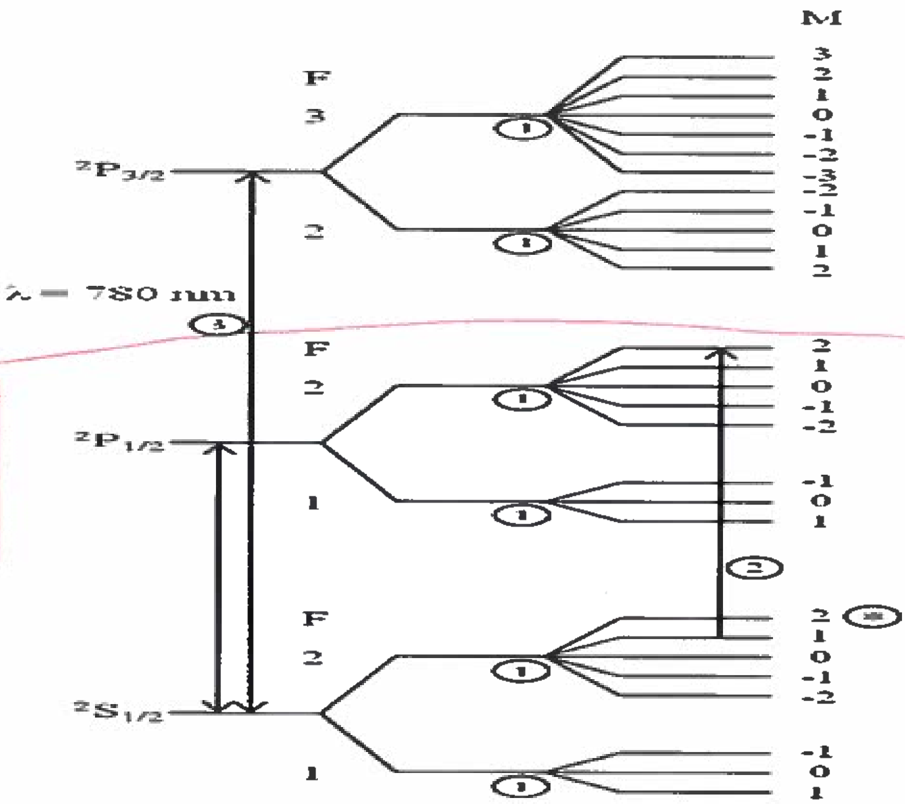
If we applied a weak external magnetic field, when the resulting splitting is very small compare to the HFS, we will produce a Zeeman Effect and that will affect the splitting of energy level.

What is Zeeman Effect?

The Zeeman effect refers to the split of spectral lines into several components when the atom is subjected to a magnetic field which aligns the magnetic moment of the electron along its direction, this split in energy invokes the degeneracy of states presented before turning on the external magnetic field.

Also the next figure will make things clear to understand.

Main theory is missing.




Clearly the picture shows the effect of magnetic field on **M** side

important part.

## What Is OP?

As I mention before OP is a technical way that used to study the discharge of energy stat and the effective of the earth magnetic field and what is the effect of an external field to the split of the energy stat.

doesn't make sense

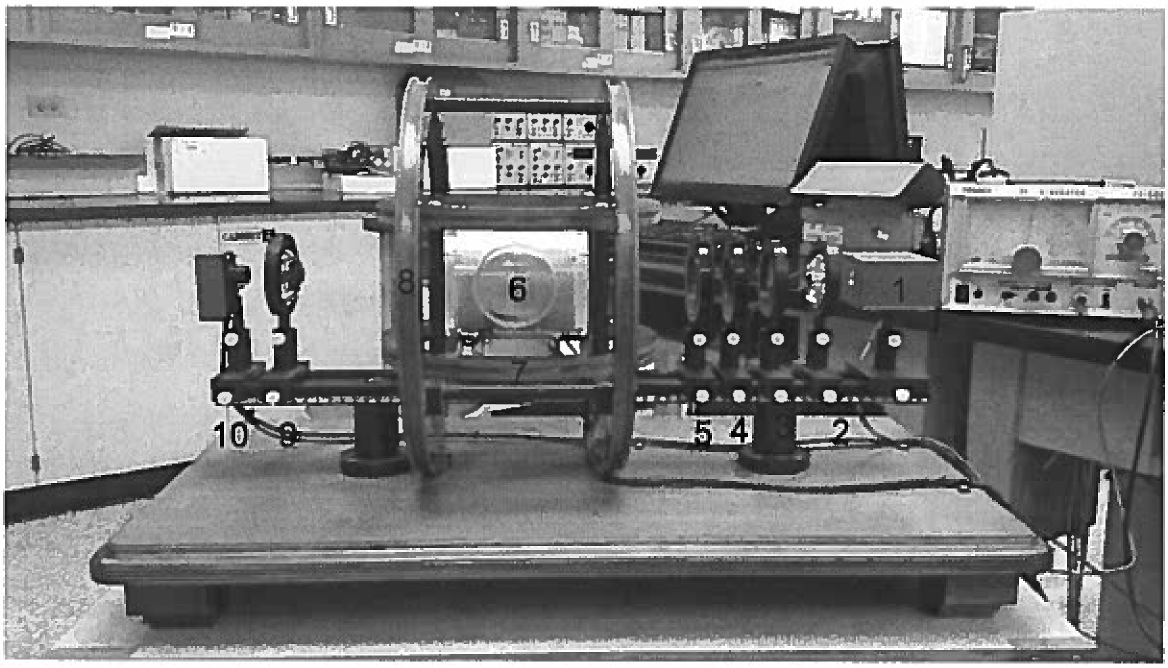
Also, OP used to deferent purposes but that depend upon that experiment itself. For example, if you need to study the HFS "Hyperfine Structure" then you will need to apply a magnetic field that is higher than the magnetic field you need to see the Zeeman Effect; otherwise you are going to Zeeman Effect instead of HFS.

Doesn't make any sense

## Experiment

## Apparatus

In OP we have the instrument from TEACH SPIN Company which is a company that makes a good instrument with its lab manuals. So we will see the instrument together and I'll explain the part of instrument and what it is for.




That picture has been taken from the lab on the instrument that I was work on it. Now I would explain all the part and its work by numbers:

1- Discharge Lamp: It is an RF oscillator with oven that continues gas on it and bulb. In the gas bulb there is a metal of Rb and buffer gas "xenon". RF electric caused the collusion between ion and atoms (both buffer gas and vapor Rb). Then atoms be either ionized or enter to an exited state. Rb in the lamp in its natural isotropic concentration, 28% $Rb^{87}$, 72% $Rb^{85}$.

2- Plano-Convex lens: that is a lens which concave from one side and plan from other side to adjust the light that come from the lamp.

3- Interference filter: 50 mm to keep out the inter fear between the wavelength. By the way we are interest in 780nm and 795 nm.

why ?

4- Linear polarizer.

5- ¼ wave plate: when the polarized light com to the plate it allowed it to convert to circular polarized light.

6- Rb absorption cell: the place where the gas and oven in.

7- Vertical magnetic field.

8- Horizontal magnetic field.

9- Plano-Convex lens to collect and concentrate the light on the detector.

10- Detector

## Optics Alignment

It so important to know that if there something makes the experiment goes in the right direction so it is the alignment. And hear I'll put the alignment as it in the manual and what I make or if I make it probably:

1- Place the lamp near the end of the rail (the rail must be made of wood to decrease any noise that can be happened).
2- Place the photo diode detector PD at the end of the rail.
3- Locate the Plano-convex leans so that the hole in the lamp is at the center of the lens. Do the same things to all lenses and be sure that it has the same arrangement seen in the picture.

4- Know you have to turn on the oven to maximize the signal and minimizing the noise.
5- After that, you have to adjust the height of the lenses to maximizing the signal coming from the detector.
6- The height of the lamp, detector and lenses almost 3.4''.

## Magnetic Field

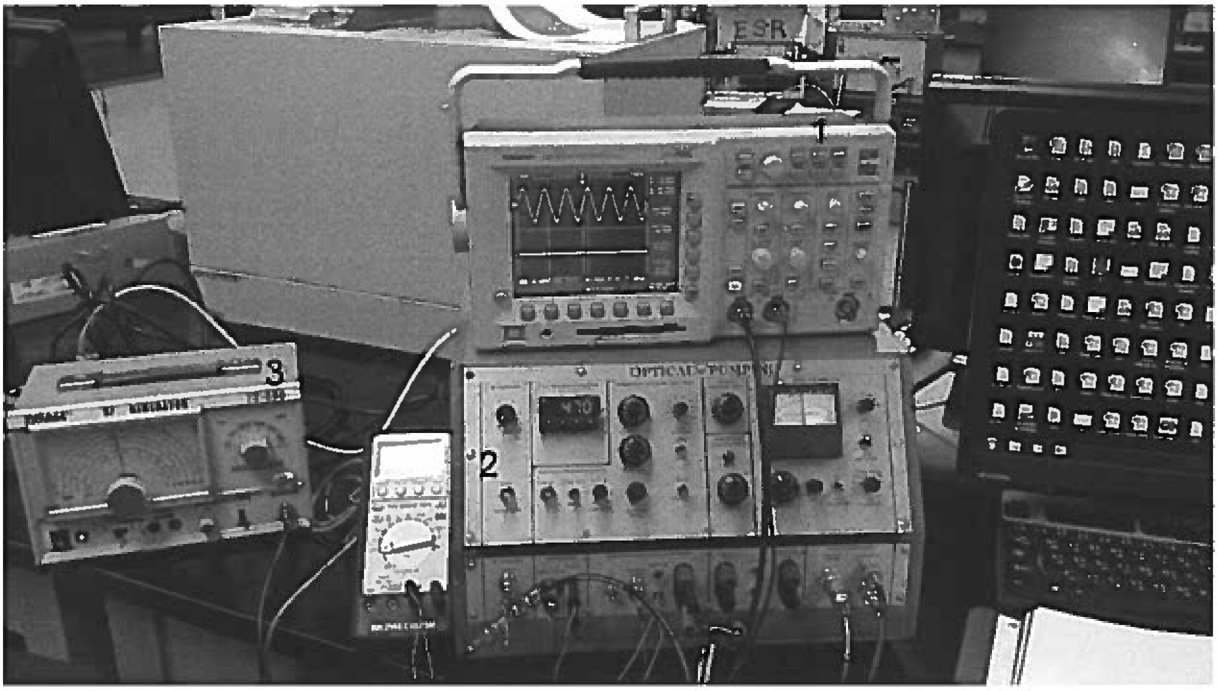
All the magnetic field used in this experiment is a DC magnetic field produced by Helmholtz coil. The coils made of copper wire and it have properties listed in the following table:

| | Mean Radius(cm) | Turns/Side | Field/Amp ($Tx10^{-4}$/Amp) | Maximum Field ($Tx10^{-4}$) |
|---|---|---|---|---|
| Vertical Field | 11.735 | 20 | 1.5 | 1.5 |
| Horizontal Field | 15.79 | 154 | 8.8 | 22 |
| Sweep Field | 16.39 | 11 | 0.6 | 0.6 |

what is this for?

## Oven and RF generator

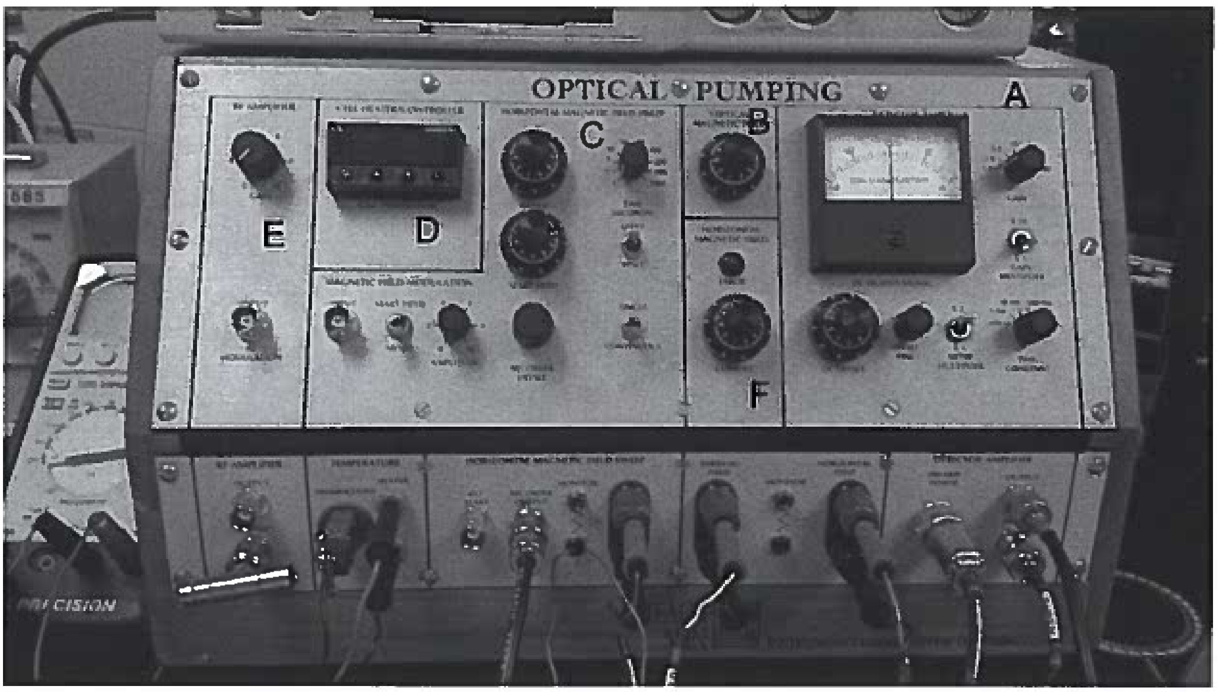
Hear I'll post a picture of the "control room" as I like to call it and the RF generator.




1- The oscilloscope.
2- The main control (I'll put a good picture with explanation next page).
3- RF generator.

## The main control

Here is the picture with a small explanation of the control board where you can control the signal and the magnetic field>




A- Detector Amplifier: which contain gain; gain multiplier, time constant, DC offset, meter multiplier and ammeter. All these switches is to keep the signal in the scale.

B- Vertical magnetic field: to increase or decrease the magnetic field cussed by the vertical component.

C- Sweep field: which contain time, start field, recorder offset and all of these are to control the horizontal sweep field and to keep the signal on the scale.

D- Heater controller where you can increase or decrease the temperature and goes to thermal equilibrium.

E- RF amplifier: usually we don't deal with it because I can control the RF signal from the RF oscillator.

F- Horizontal magnetic field current to control the horizontal field.

## Before Started

You must know that if you don't do this part correctly you wouldn't find a good result that you could use. Hear I'll follow the writ up step by step (as I did when I explained in the alignment):

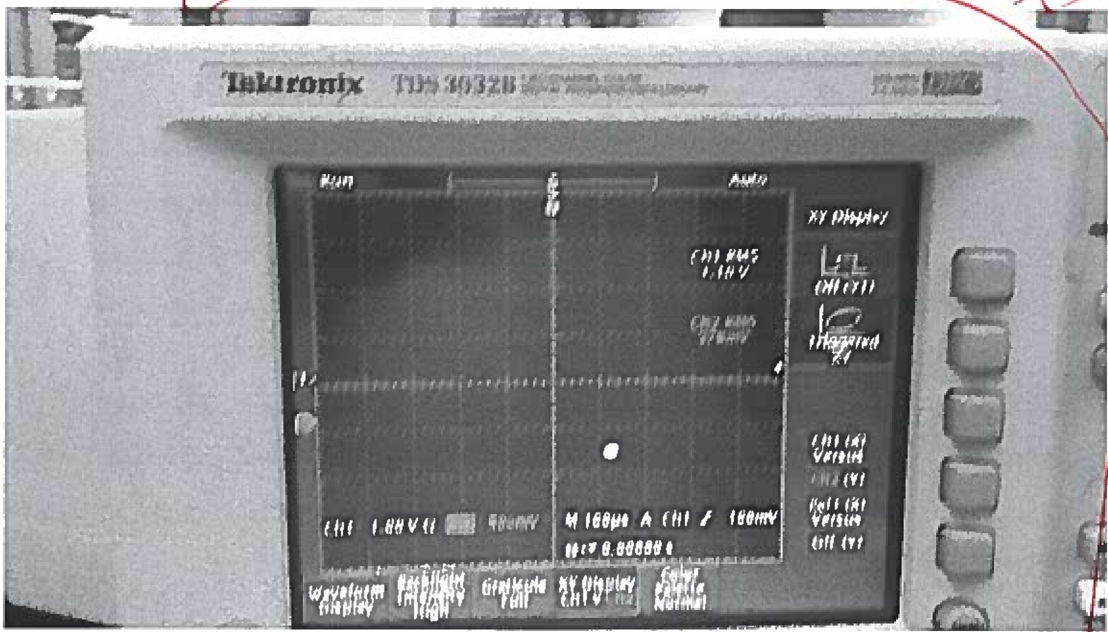
a- Hear he talk about how is the external magnetic field effect the result you get. By the way this experiment one of the most sensitive experiment that I'd ever get. Also light make a big deferent in getting a good signal.
   **Problems to solve?**
   I was thinking how I can get off the noise that I found in the ammeter such a way that I found a better result that I found in the class time. The class time was in the morning and our lab is a kind of lab and a way to pass through to the next class room. Although, it's the class time and I have to share the lab with my friend, which is something make me some time nerves. I ask the professor to let me come in the afternoon and he gave me a pass to attend using my ID card to open the lab in the night. Hear the problem solved, when I came in the night I switch off all the light and make the environment good for a good result.
b- Alignment the plat with the earth magnetic field. For this step I used my phone to get north exactly.
c- c through e was explained earlier.

f- When you tear on the light you must wait for 20 min to let thermal equilibrium to occupy. My suggestion is to wait for a 30 min at least spicily when you start it from rest because it is so cold at that time and don't be harry.

g- Hear he gives you the alignment number to put it in control board like DC offset, Meter multiplier and so on.

h- Maximizing the optical signal by adjusting the two lenses.

i- Zero field transition, the most difficult things in this part that it tacks along time to be established. Using oscilloscope with X-Y axis that wear X-axis is the Horizontal sweep field and Y-axis is the Detector output. Set the vertical field current to 0.33A and the sweep around 0.30A. Hear I have a good picture of the zero fields.




Although the picture is not very clear but its seen that the yellow point comes to be in the dip of the scale, so it is in the zero field now.

## Absorption of Rb Resonance Radiation by Atomic Rb

Purpose:

1- To make approximation measurement of cross-section for the absorption of Rb resonance radiation using atomic Rb.
2- Compare the value you get with theoretical value.

Procedure:

1- First of all you have to remove the liner polarizer and quarter wave plates and keep the filter only.
2- As been discussed in the previous page the field now is been putted in the lowest field or in the zero field transition, so to be known that the entire instrument know is dealing with that mode.
3- Using the heat cell to adjust the temperature at 300K. In this step you have to be patient by waiting for 25-30 min until the thermal equilibrium is established.
4- Know I measure the intensity of the signal, which is the voltage, and by increasing the temperature by 10K at each step. Also you have to take care that the thermal equilibrium must be reached in each.
5- The next table shows the density number increasing while the temperature increasing:

| Temperature K | Density, atoms/cubic meter |
|---|---|
| 290 | 3.3x10^15 |
| 300 | 1.1x10^16 |
| 310 | 2.9x10^16 |
| 320 | 7.5x10^16 |

| | |
|---|---|
| 330 | 1.8x10^17 |
| 340 | 4.3x10^17 |
| 350 | 8.3x10^17 |
| 360 | 1.5x10^18 |
| 370 | 3.7x10^18 |
| 380 | 6.3x10^18 |
| 390 | 1.2x10^19 |
| 400 | 2.4x10^19 |

6- After I taking the data I found the next table :

7-

| Temperature (C) | Detector Output (V) |
|---|---|
| 26.9 | 1.8 |
| 36.9 | 1.6 |
| 46.9 | 1.3 |
| 56.9 | 0.9 |
| 66.9 | 0.55 |
| 75.5 | 0.325 |

| | |
|---|---|
| 86 | 0.2 |
| 95.7 | 0.175 |
| 105.5 | 0.15 |
| 115.5 | 0.13 |
| 122 | 0.13 |

Hear you realize that I toke the temperature in C because the heater cell is stake to a C not in K.

8- After taking the data I use the equation that delivered in the Teach Spin manual:

$$I = ae^{-b\rho}$$

Where:

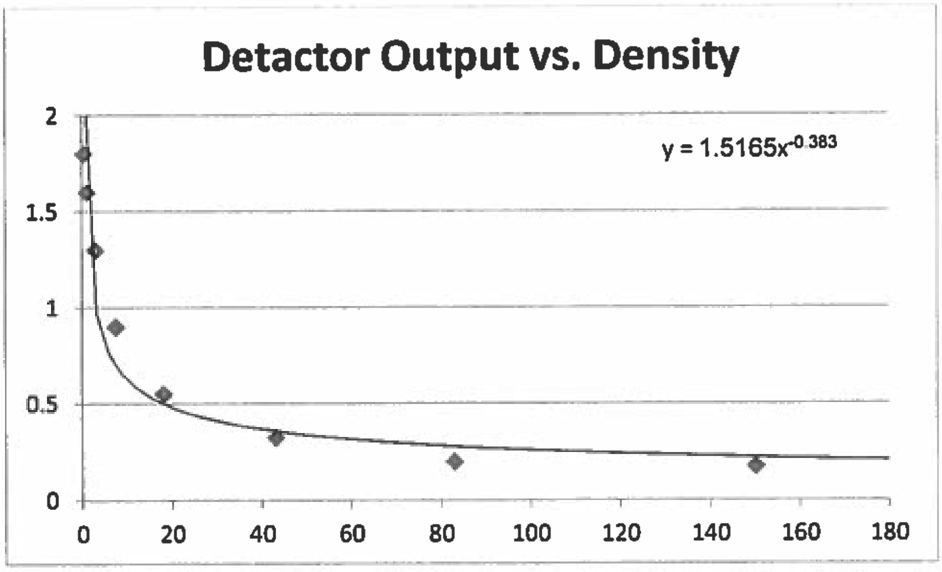
ρ= density of atomic Rb

b= cross section

Also to be more acute in the next table I'll put all the measurement that I found in a small box:

| Temperature | Gain | Gaine Multiplier | Time Constant | Meter Multiplier | DC Offset | Galvanometer | Detector Output |
|---|---|---|---|---|---|---|---|
| 26.9 | 1 | 1 | 100 ms | 2 | 0 | 1.8 | 1.8 |
| 36.9 | 2 | 1 | 100 ms | 2 | 0 | 3.2 | 1.6 |
| 46.9 | 2 | 1 | 100 ms | 2 | 2.6 | 0 | 1.3 |
| 56.9 | 2 | 1 | 100 ms | 2 | 0 | 1.8 | 0.9 |
| 66.9 | 2 | 1 | 100 ms | 2 | 0 | 1.1 | 0.55 |
| 75.5 | 2 | 1 | 100 ms | 2 | 0.65 | 0 | 0.325 |
| 86 | 2 | 1 | 100 ms | 2 | 0.4 | 0 | 0.2 |
| 95.7 | 2 | 1 | 100 ms | 2 | 0.35 | 0 | 0.175 |
| 105.5 | 2 | 1 | 100 ms | 2 | 0.3 | 0 | 0.15 |
| 115.5 | 2 | 1 | 100 ms | 2 | 0.25 | 0 | 0.13 |
| 122 | 2 | 1 | 100 ms | 2 | 0.25 | 0 | 0.13 |

Know I plot the detector output vs. density. And I get:




In the manual the writer uses Sigma Plot which is a drowning program that gives you cross section. But hear I'll use the result from the Exile graph that calculated up in the graph and it will be enough for me for some reason that I'll discus later.

The length of the absorption is 2.5cm and any point in the density graph will be a data point, so that gives:

$$y = 1.5165x^{-0.383}$$

Where:

Slope =1.5

Also -0.383 is some constant multiply the density given by this notation:

$$x=0.383\rho$$

So this constant, if you consider ρ= 20, then the value of the power factor will be 0.055.

So, we can found the cross section by the given equation:

$$0.025\sigma x10^{16} = 0.055$$

Then $\sigma = 2.2x10^{-16}\ m^2$

Hear I can compare with the result that Teach Spin manual where he gets $\sigma = 1.6x10^{-16}m^{2,}$ also he compare his result with the other equation that mention in the manual, which is:

$$k0 = \frac{2}{\Delta v} \cdot \frac{\lambda g2}{8\pi g1} \frac{\rho}{\tau}$$

Where:

λ= wavelength at the center of the absorption line.

$g_1$ and $g_2$ = statistical weight of lower and upper stat.

τ=life time.

Δv=Doppler width of absorption line.

And for the manual he chose the parameter as a constant parameter where you can found it in the inter net. Where that yield to a cross section $\sigma = 15x10^{16}$.

Hear also I have to notice that in the manual and some other sources you can realize that the experimental value is much less the theory that has been calculated.

**Conclusion about this experiment:**

This experiment give me a good result but it needs some restriction like coms in the night to have a good result and not getting noise. Also the cross section that I have discussed before is a measured value that should be considered to be approximation value not more that as it written in the manual. Knowing that sources of error make my result eight times less than the theory but it is reasonable. One of the biggest sours of error is the cursory variation of density with temperature.

## Low Field Resonance

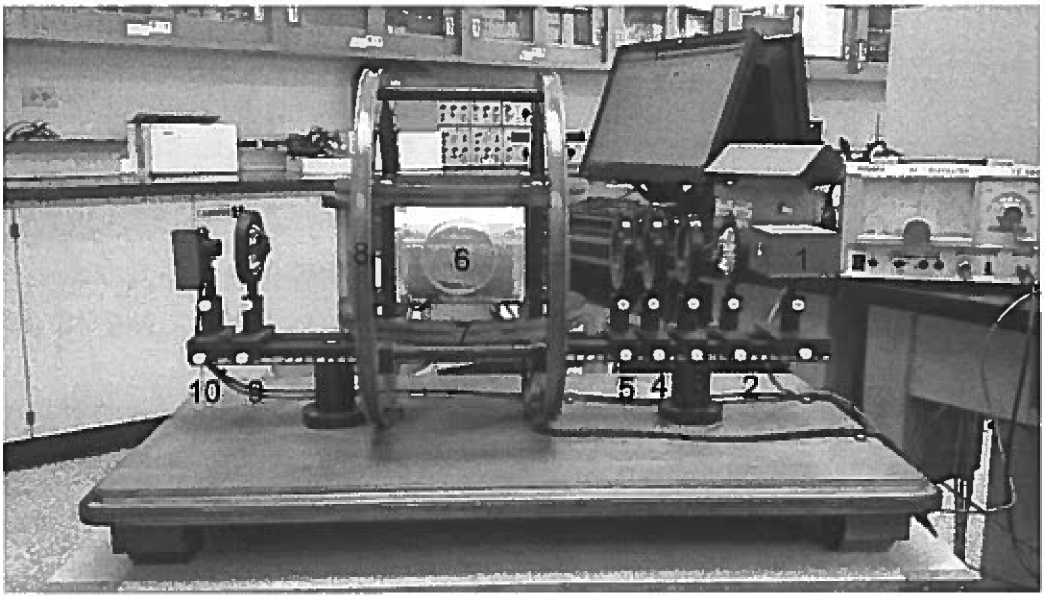
Purpose:

Studding the effect of low fields in measuring the nuclear spin. See the Zeeman effect. To be confine in playing with the coil and see the effect of fields into calibration.

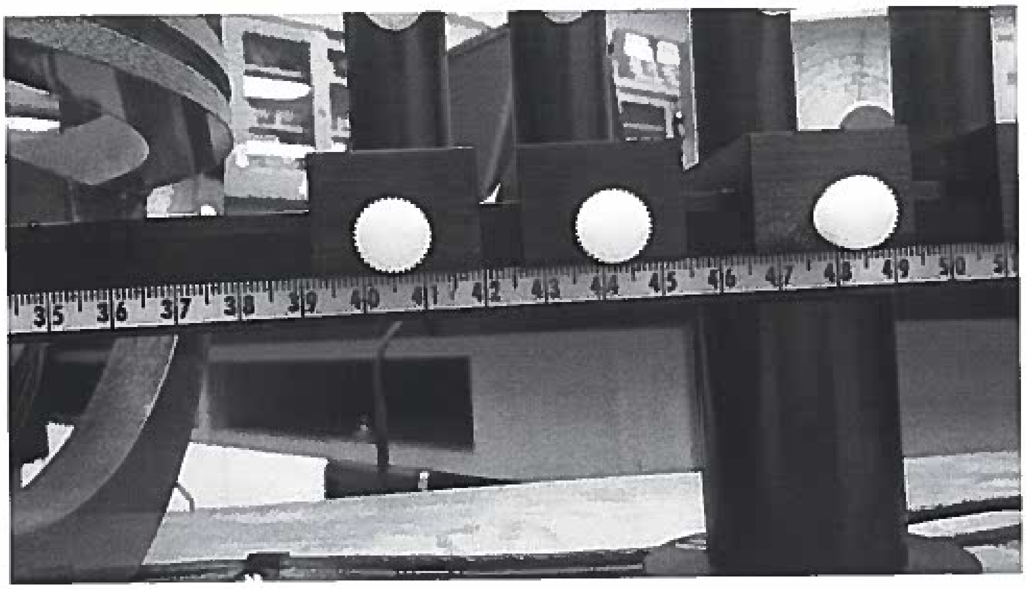
Procedure:

First of all , I have to put again the linear polarizer and the quarter wave plate to its place and be sure that it gives me a maximum like before . And now I'll put the step one by one with picture to be in the same way that I have done in the lab:

1-If you put the instrument as describe before then you will end up with this picture:




Also, polarizer and the quarter wave plate that I returned back have been adjusted again in a new location:




This picture shows the place for the plats

2-Adjest the instrument table with the earth magnetic field. I use a campus in my phone to alien the plat.

3-To get off any noise I have to leave my phone and any metal far away while I do the experiment.

4-With no RF applied you have to start the experiment and the magnetic sweep field must be zero.

5-I put the current through the horizontal magnetic field to zero by unplug the banana plugs. Trying to put the vertical magnetic field in the minimum width is a matter of seeing the width properly in the point of zero transition.

6-By putting the output in the y-axis of the oscilloscope and the current of the sweep field in the x-axis of the oscilloscope. Set the temperature to be around 50 C and let the thermal ~~equilibrium to be occur~~.

- what is the use of sweep field?
- What does horizontal comp. of earth magnetic field do?
- How do you get optical pumping
- Why do you use radio frequency!

Spirit of experiment is missing

**Measure $g_F$**

We know that we have in this experiment two different isotopes of Rb and each one of them have different spin. To find that I have to measure $g_F$, by measure the frequency of each one with a well-known value of magnetic field. Measuring the magnetic field will be done by the next equation:

$$B = 8.991x10^{-3}\frac{I\,N}{R}$$

Where:

I = current

N = number of turns in the coil.

R = the mean radius.

In the front panel there is a monitor and its contain a one ohm resistor, so its equal to the voltage that given in the front of the oscilloscope to measure sweep field current.

The field B measured with a parameter of N=11,R=0.1639m and I=0.356amps and that yield to B=0.215(gauss).

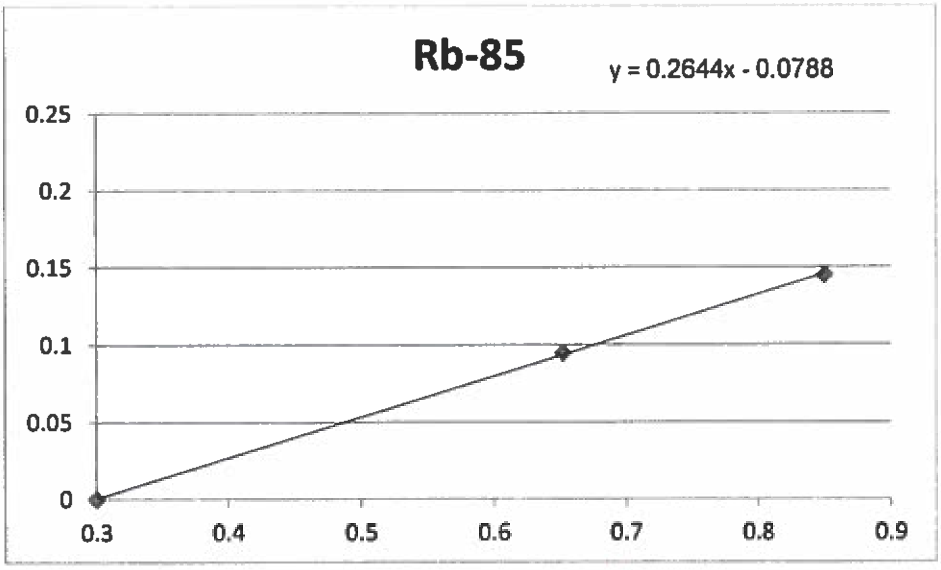
Now I apply the RF signal by turn on the RF generator and putting the frequency on 150KHz. Now I use the horizontal magnetic field to find the Zeeman resonance.

Main jest of experiment is not present

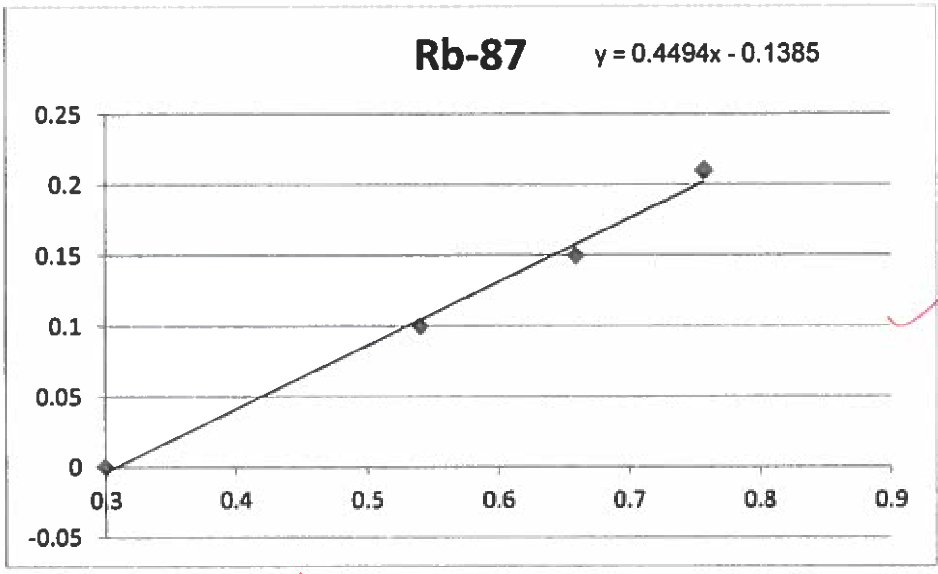
- why vertical field has to cancel the vertical magnetic field comp of earth magnet.
- what value gives you a sharp dip.
- what is the use of horizontal value.
- Why did you use filter?

Spirit of experiment is missing

## Low Field Zeeman Effect




caption




caption

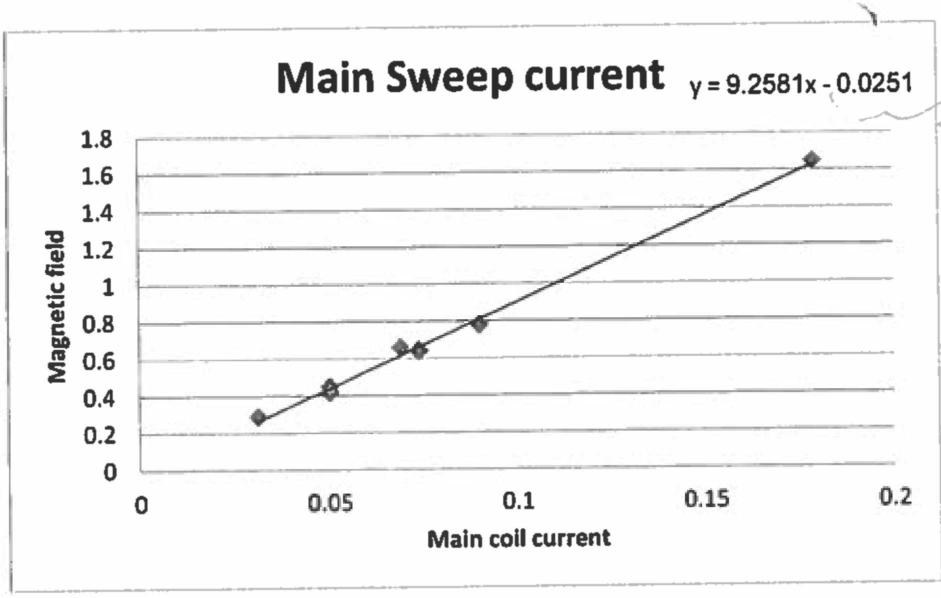
Getting the ratio of the two slops in the privies graphs yield 0.45/0.26 is equal to 1.73 and the theoretical is 1.5.

Table the data

## Mine Field Calibration

To do this part so important to let the main field be in the direction of the sweep field and it must be known that I have to use both the mine coil and the sweep coil to do this part. The next table set the vale I get( actually not all of them taking by me, some of them from the manual and that related to some reason will be notice in source of error part):

| Freq MHz | Total field | Sweep current | Main current | B from sweep coil | B from main coil | Isotope |
|---|---|---|---|---|---|---|
| 0.2 | 0.2861 | 0.356 | 0.0312 | 0.005 | 0.29 | 87 |
| 0.2 | 0.43 | 0.35 | 0.05 | 0.002 | 0.45 | 85 |
| 0.3003 | 0.429 | 0.31 | 0.05 | -0.004 | 0.42 | 87 |
| 0.3003 | 0.65 | 0.34 | 0.069 | -0.0024 | 0.66 | 85 |
| 0.4002 | 0.5719 | 0.197 | 0.074 | -0.0716 | 0.6435 | 87 |
| 0.4002 | 0.8578 | 0.662 | 0.074 | 0.2148 | 0.643 | 85 |
| 0.5002 | 0.7148 | 0.205 | 0.09 | -0.0667 | 0.7815 | 87 |
| 0.5002 | 1.0722 | 0.785 | 0.09 | 0.2906 | 0.7816 | 85 |
| 1 | 1.4291 | 0.121 | 0.1786 | -0.1185 | 1.6482 | 87 |



From the graph we can say that my result not far away from the manual calculation.

Now we left with the $g_f$, where the two current that I measure for the isotope are 0.85 and 0.65 giving a value of 0.513 and 0.392. From each one of them I must reduce 0.215 , because it is in the opposite way of them. So thy will be 0.298 and 0.177.

The resonance frequency determent from the equation:

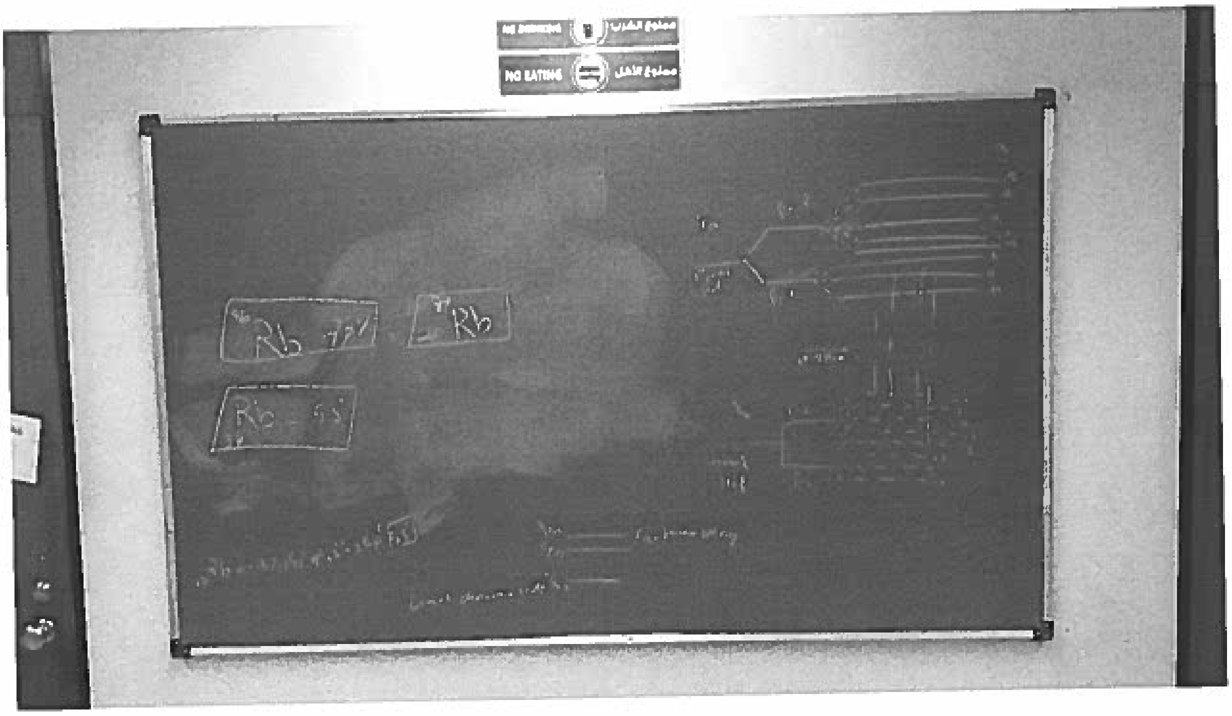
$$v = gfX\mu\frac{B}{h}$$

And that give me a $g_F$ of 0.3 and 0.5. And that give me a spin of I=5/2 and I=3/2.

I have to mention this part at the bingeing but I stuck with some calculation, any way the vale hear is used in the above reign.

**Conclusion:**

Finally when I finishing this report I found that I cross a long distance to knowing and studying this experiment. This experiment told me to be patient and put me in the face of that saying "If you don't give you don't gain". At the last part of the experiment I figure out that my instrument dose not respond to any changing in the current and field, so I use the table in the manual to complete the calibration. Also hope my friend have a beater luck to get more acuter data that I found. In my opinion this experiment must designed to be more efficient so that it not take a lot of time as it happen to me. Putting everything in your min all the time make you concentrate in your goal and hear is picture to the board next to me where I was doing the experiment.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Rb

# NMR Experiment

## Objectives

The general objectives of the NMR experiment is to familiarize with the instrument itself and the nuclear processes and interaction that involves magnetism and electricity.For the specific case the objective was first to identify the properties of FID decay curve and its Fourier transform in the different intervening factors for different materials or samples..Then it was to specify or let`s say quantlfy this relation by the measurement of T1 and T2 and other important factors.

## Introduction

NMR experiment overwhelms a huge physics background in various fields which range for quantum mechanics to electromagnetism and wavelets .The process is stimulation of the natural magnetism that is produced by the nucleus rotating about itself.

From here we get the rule:

$$\vec{\mu} = \gamma \vec{I}$$

Where μ is the magnetic moment and I is the magntic momentum.

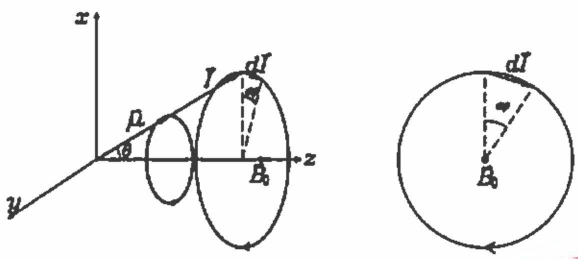
This field is prdouced and precesses along the z-axis like toy-towe and varies acoroding to the magnidtude of the x,y and z components of the magnetic field.

This determined by the gyromagnetic ratio which is a quantum value :

$$\gamma = \frac{g\mu_n}{\hbar} = \frac{ge}{2m_p}$$

Where g is the spectroscopic splitting factor,e is 1.6E-19 and mp is the mass of the protons.

These values are in the no external field case but on an external field Bo is applied we get due to μ a torque that rotates the nucleus.The figure below shows a demonstration of the torque.



The rotation of the nucleus happens such that the nuclear magnetization presses along the z-axis (Bo axis) with a certain frequency called the Larmor frequency (wL):

$$\omega_0 \equiv \frac{d\phi}{dt} = \gamma B_0 \ ,$$

The magnetic field Bo splits consequently the spin splits into two levels with I=+1/2 and -1/2 with the energy difference is :

$$\Delta U = U_- - U_+ = \gamma \hbar B_0$$

When the nucleus transfers from the higher level to lower level of energy the emitted phton is governed by the following relation where their frequency is the dependent variable and the one that can be manipulated and the one we will be playing with in the experiment for getting the signal .

$$\hbar\omega_0 = \gamma \hbar B_0$$

The applied magnetic field is generated from an RF generator circuit with a frequency in the order of MHZ so to produce the sufficient magnetic field for the observable change.

This magnetic field should be circularly polarized and in the same precession access with the angular spin so to change the magnetic spin and the frequency.The probability that the spin will be excited from ml=+1/2 to -1/2 will be the maximum when the magnetic field is precessing with the same frequency with magnetic moment and decreases as the frequency moves away.

When we are using a sample there is bulk behavior which includes opposing cases so we can measure the magnetization by measuring the net effect of all the spins.Usually the effect is negligible and the net magnetization becomes exact zero.In other occasions there are some remains which are determined by the following ratio:

$$\frac{N_+}{N_-} = \frac{\exp(-U_+/kT)}{\exp(-U_-/kT)} = \frac{\exp\left(+\frac{1}{2}\gamma\hbar B_0/kT\right)}{\exp\left(-\frac{1}{2}\gamma\hbar B_0/kT\right)} = e^{\gamma\hbar B_0/kT}$$

When an external magnetic field is applied there is a slight distribution to the equilibrium maintained by the above formula which does not sustain for a long time and returns to its original position.In the application of the field time the magnetization can return to its original position as the field is oscillating and not constantly applied as the protons continuously exhanges the energy and magnetization with the surroundings.

The z-component of the magnetization is always not zero because the moments of the antiparllel is more than that of the parallel and the tends to return to the magnetization before the action of the magnetic field the time that the Mz returns to its equilibrium position is called the spin relaxation time or this T1 which I will investigate later in the experiment.

By symmetry means Mx and My are mostly zero or oscillates with the average at zero.If any one component have been excited then it will undergo a series of nonlinear variations in the magnitude and direction and then decays to its original position in a time called spin-spin time or T2.

These two times where the main values measured in the experiment procedure in addition to other important steps that will be highlighted thoroughly later on.The cross product of the magnetization and the magnetic field gives the direction of the produced voltage by the faraday's law :

$$\mathcal{E} = -\frac{d\Phi_B}{dt}$$

So the voltage is our mean in determining the change in the magnetic field magnitude and direction.When the magnetic field starts to rotate we start having two spin times as mentioned earlier one fro the x-axis and y-axis component spin-spin relexation time and one for the z-axis component T1 which is for spin-lattice relaxation time. There is also a third generated due to the external inhomogeneity in the magnetic field which leads to spin-spin dephasing time that sometimes dominate the other two effects.Of course , the magnetic field z component in this case is rotating at the Larmor Frequency for optimum uniformity .Collectively the third relaxation time is related with the first two by this relation:

$$\frac{1}{T_2^*} = \frac{1}{T_1} + \frac{1}{T_2} + \gamma \Delta B_0 \, ,$$

The best width for the resonance frequency is 1/T2*.The main values is T1 and T2 that describes in the best way the characteristics of the magnetic behavior of the material used.There is different ways to know them as we will see in a moment.

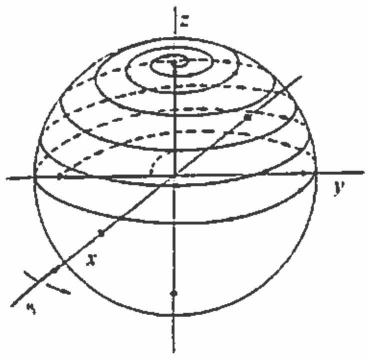
The main magnetic field is composed of 3 components as well known.Our goal is to find the rate of relaxation from the resonant frequency of precession.

**Experiment**

In this experiment we must verify different aspects of the behavior of the sample used under external magnetic field either constant one or rotationally varying one.There are different coils used in order to control the magnetic components in all dirserctions.Moroever, an electric current of oscillating nature is produced from the coil in order to control the frequency of the magnetic field of the nucleus or protons in some cases.This control is done by the application of consective beats or pulses.There are mainly two important pulses tyoes 90 and 180 degree pulses.The 90 degree pulse rotates the magnetization from the z-axis to the x-axis whcile 180 degree pulse rotates the magnetization to the opposite side in the same axis.As we agreed that a precision occurs here is the transformation of the coordinates system in order to be on the same reference frames with the rotating magnetic field B0 which will eventually vanish.

$$\begin{aligned} x' &= x\cos\omega_0 t - y\sin\omega_0 t \, , \\ y' &= x\sin\omega_0 t + y\cos\omega_0 t \, , \\ z' &= z \, , \end{aligned}$$

B1 is applied to have the same coordinate system thus it will appear to be constant.The motion of the moments with the application static magnetic field and the rotating magntic field B1 wihy frequency of precesion w1 the motion of the moments μ will rotate on this form.




In a bulk of the moments the magnetic field will first initially in the z-axis and then precess around the z-axis which will induce a voltage that is detected by the coil and called **Free Induction Decay (FID)**.This is one form of 90 degree pulse as discussed earlier.

The magnetization Mo of the sample as the experiment start depends on the following experiments:

$$M_0 = N\mu \tanh\left(\frac{\mu B}{kT}\right) \approx N\frac{\mu^2 B}{kT}$$

Where μ is the magnetic moment,B is the magntic field,K is the Boltzmann constant and T is the temperature.

The magnetization builds from zero to an equilibrium value by following this relation:

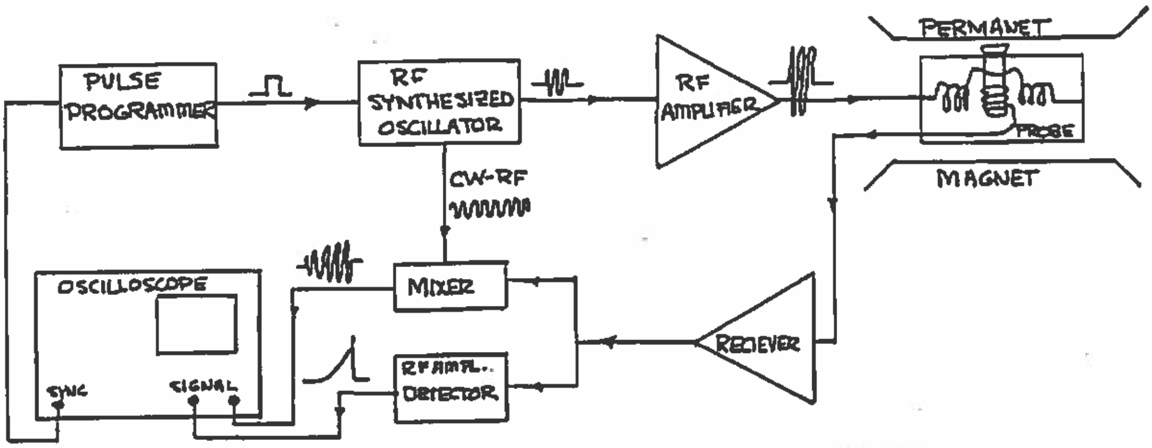
$$M_z(t) = M_0(1 - e^{-\frac{t}{T_1}})$$

## Apparatus

In the apparatus used there are several important components for the production of the 90 degrees or so pulse that rotates at the time period:

$$t_{\pi/2} = \frac{1}{4}t_1 = \frac{\pi}{2\gamma B_1}$$

This brought be the presence of several components which as the RF generator, magnetic coil,receiver,pulse



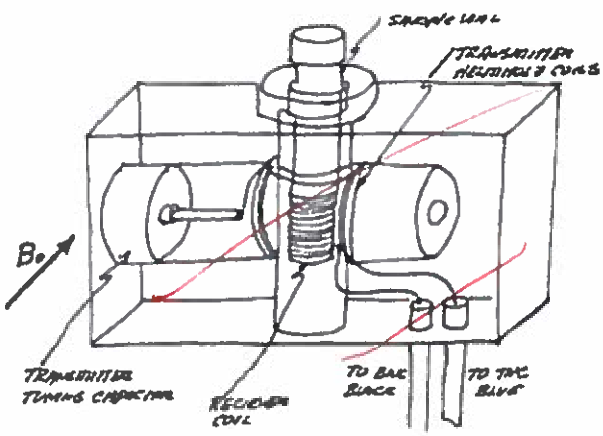

programmer,lock in amplifier and synthesizer.

**RF generator**

In this generator we pass a current with varying frequency according to the RLC circuit in the coil that itself produce a varying magnetic field in the same frequency.The Rf generator have a certain frequency where we can attain the maximum at and similarly other frequencies where we get small values and also it have a phase that is all controlled by the main frame and mainly by the pulse programmer.

**Magnetic coil**

i mean here the different permanent magnets used in this experiment that have a gradient controlling the different axes in order to control the FID signal produced by the sample in surrounded by the coil in the magnetic loop.This figure visualizes the magnet:



For coils,they are divided into horizontal, vertical and gradient coils that manipulate with the magnetic field according to our desire in the experiment.

**Receiver**

The function of signal receiver is to receive the signals from the magnets and in the same place directed toward the pulse programmer in the form which can be understood or dealt with by the synthesizer.This form comes after smoothening using RC filters and ~~suspects to~~ changes in the frequencies.

**Pulse Programmer**

Here most of the work occurs where the pulse can be manipulated in terms of phase,frequency and other factors so we can get the best possible signals to be sent to the oscilloscope .Moreover, this part have the generation of the I and Q signals by performing Fourier transoms and other transforms.

**Signal Synthesizer**

Here we send the signal to the oscilloscope which can be in the form of one or several signals that have several properties .These properties are controlled obviously in the synthesizer as time difference ,signals length and number of signals.Moreover, here we receive some information from the Pulse Programmer and send it to the Lock-In Amplifier's this part also act as a transformer

## Procedure

In this experiment the main goal was to generally verify the behavior of the water and light mineral oil .First was the setup of the experiment which did take a lot of time as the machine is complicated and involved several apparatus as shown previously and also the manual procedure was very long.Then we started to run the machine and verify its performance and then before we actually start the sample we tune the detector using the tubing capacitor in order to get the possible signal for the FID later .The shape of the signal must be similar to the one shown below.

Then we set the resonant frequency to a certain value where we see the frequency having the highest amplitude in all frequencies .This value is about 21.6-21.4 MHz.The phenomena arises from simply that at the resonant frequency the non z components of the magnetic field is minimum therefore, the rotation here is maximum.Then comes the set up pf some conditions in the apartus to mesure the signal properly like different tunings and checkup of the wires which is important from the operation of the experiment properly.(There are some parts which were supposed to do as Lock-In amplifier but due to the restricted time we could not which thus have affected our sweep I wed into modify it later to this mode as expected).

**I-Observational experiment**

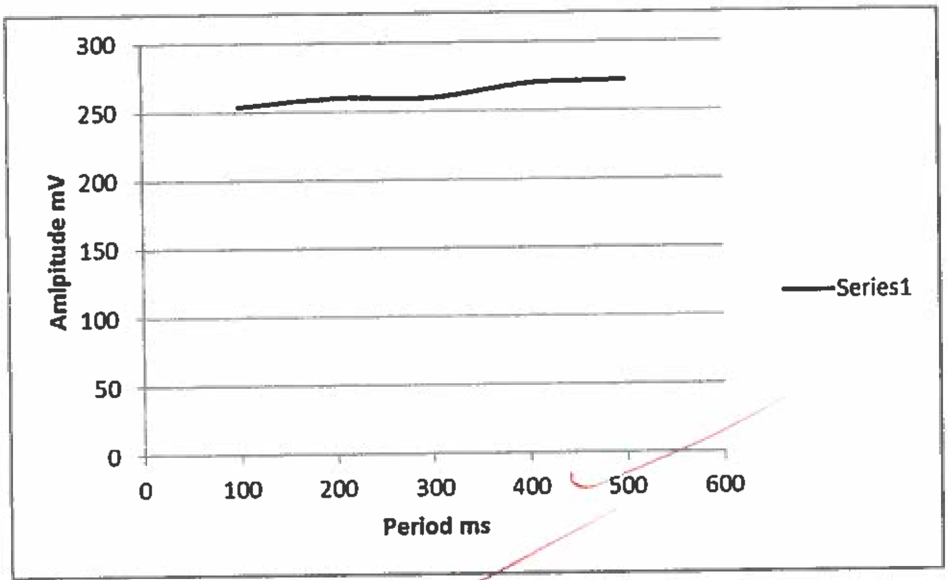
After a series of manipulations with the frequency I got the proper resonance frequency.Then there were the Q and I output which represents the Fourier transforms of these signals which have different properties in the I or Q channel.The produced signal were initially for light mineral oil which was then manipulated and its behavior in relation with certain factors were verified and some changes were done .Additionally, the temperature maintaining circuit where closed in order to stabilize the temperature and I made sure that the gradients for X,Y,Z and $Z^2$ axis were set at zero.

a) We can know that we have the angle by inspecting the change in the amplitudes corresponding to the changing length of the pulse and from there we can determine if we have a 90 for maximum amplitude or 180 for minimum .Similarly for 270 the next maximum you get after the minimum corresponds to the length of 270 pulse.Usually the 90 length pulse is half the 180 length pulse and we partly use this fact to facilitate the measurements later on.

b)The average magnetic field is 0.881 T

d)As you increase the filter time constant the amplitude of the signal of the oscilloscope will decrease but the wave will get even smoother which is explained properly when understanding the function of the TC filter in any circuits

e)This is the graph of the amplitude of the 90 pulse against the period



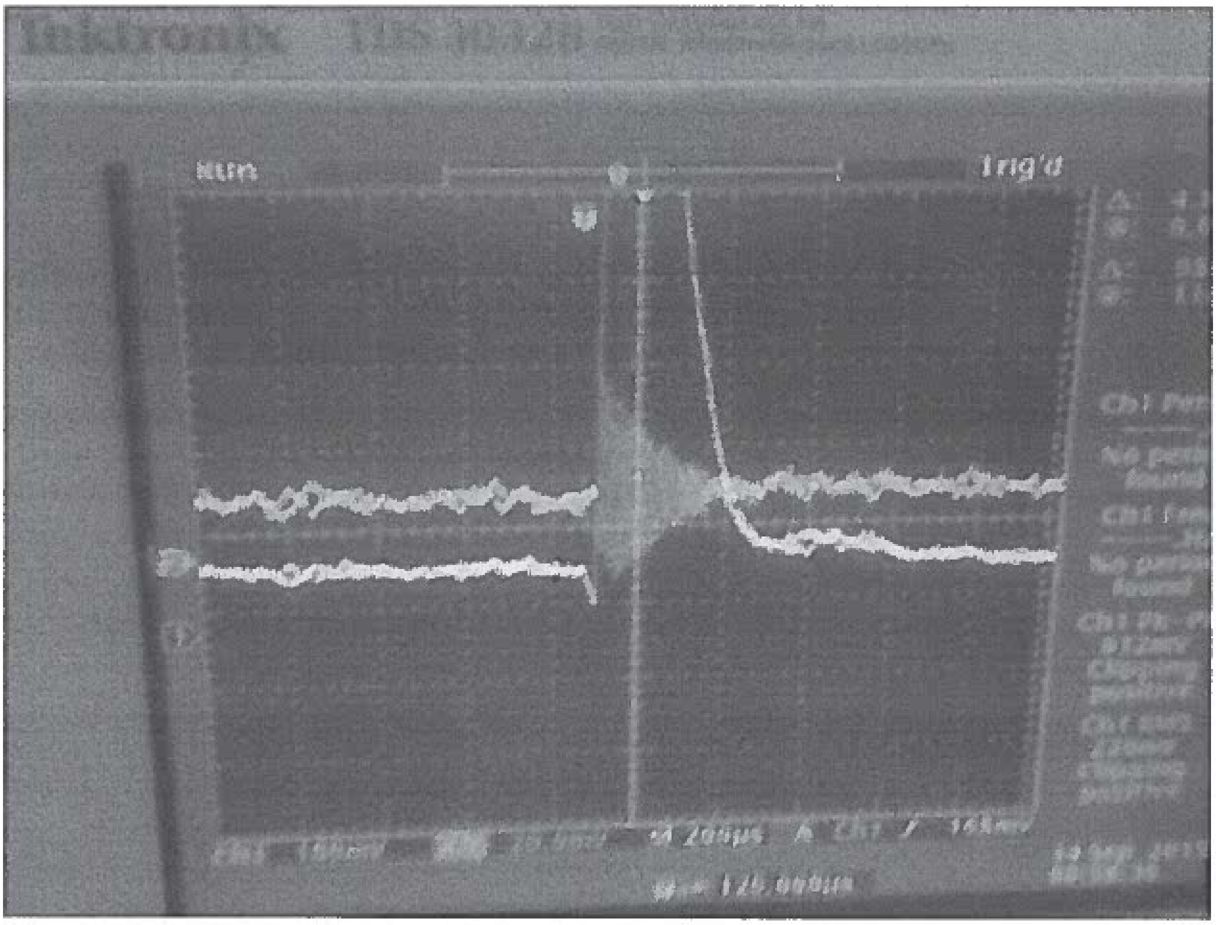

The shape indicates that there is slight increase and generally it is constant

f) Regarding the resonance frequency we can figure it out by measuring the amolitude pof the oscilloscope FID signal from the Env out.From here we find the frequency that produce the highest amplitudes with out varying other factors and this frequency will be the resonance frequency.

g) Obviously there will be a signal just away from the resonance frequency that decreases as you go away with some local peaks .What happen is that as we go away from the frequency there is still some frequency that is more than the filed in that direction governed by the equation:

$$(B_0 - \frac{\omega}{\gamma}),$$

j)I got a longer signal than the one showed that is due to manipulating with the magnetic field gradients and the frequencies.This is the shape:




Label & captions

k)After repeating the experiment with the water that properties are or less the same qualitatively but there some differences in the resonance frequencies obviously.Also the amplitudes are different and the general behavior of the wave changes slightly when changing the frequency. I or Q channels a showing Fourier Fast Transforms have different frequencies in water and so its shape on magnification seems barely different .

**2-Obtaining 180 pulse**

The process of obtaining the 180 degree pulse is important due to its significant later on in finding T1 and T2.The special part about this experiment is that theoretically the 180 degree pulse must have small amplitude or actually zero.This contradicts with our findings in the experiment which confused me a lot in this experiment.

**Two Pulse Experiments**

In this experiment there is two forms a single FID signal as the one discussed previously and the spin echo signal that constitutes of several oscillations and this produce many signals.This process arises due to using two or more signals that will produce resonances at different points.

The signals are separated by a time difference that I will use in order to determine relaxation times T1 & T2.

Determination of relaxation times is considered to be the core of the NMR experiment and the most understood and fruitful experiment in the NMR.The main goal is to determine the relexation times by merging two or more signals with a time difference between the m.The sample used in this experiments water that produced special result different from the ones of light minereal oil due to the difference between the water and oil composition is explained earlier  in the theory part.There were seveeal difficulties that encountered me in this experiment that I will talk in the next few pages which arises from both the experiment and the instrument used.

**Determination of T1**

T1 as explained earlier represents the is spin-lattice relaxation time.This experiment is performed by applying 180 signal then 90 degree signal after a time separation. This is because as the first magnetization 180 degrees inverts the signal from Mz to –Mz. However, this magnetization cannot be detected by the spectrometer as it is not on the x-y plane. So what happens is that the 90 degree pulse is the one that rotates the signal to the x-y plane so it can be found. The main readings in this experiment are the voltage which is proportional to the voltage versus the time separation.The relation is shown in this equation:

$$\ln\left[\frac{M_{eq} - M(\tau)}{2M_{eq}}\right] = \frac{-\tau}{T_1}$$

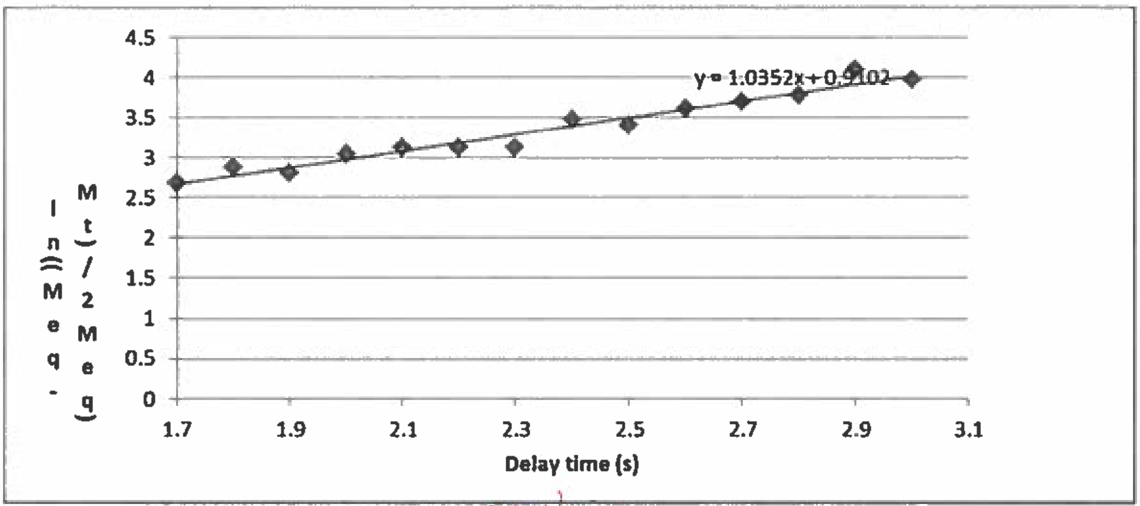
Where M is the magnetization ,M eq is the equilibrium magnetization, T1 is spin relaxation time and tau is τ is the time separation between the consecutive two signals in this case.From this equation we can deduce that the slope gives us T1.

So the procedure will logically start with finding the 180 degree pulse and the 90 degree pulse which is done earlier.This step is very important in the matter of the efficacy of the experiment.Then I applied the two signals consecutively for various values ranging from 1.7 – 3ms.There was a great problem in the data stability and the display in the oscilloscope.Moreoverm the steps were not clear that much.There is an important point that involves taking the lower values of the two peaks you get where the 180 degree lone dominates more as the separation of the dealy increase because as this time the spectrometer cannot detect the signal for longer period than before.This fact have relatively limited the maximum equilibrium magnetization I could reach as after delay equals 4 seconds the intend signal could not be reached.

The results where oscillating and not stable to an extent that the lowest value of the highest averaged reading is lower than the highest value for the lowest arranged readings.This inspired me to average b y using three or more readings as shown in the data table below.The set of data was measured in the closed temperature loop mode .These were readings and the graphs.

| τ (s) | M1(V)-1 | M1(V)-2 | M1(V)-3 | AVERAGE | ln((mq-Mt)/2Mq) |
|---|---|---|---|---|---|
| 1.7 | 1.34 | 1.4 | 1.4 | 1.38 | 2.677278542 |
| 1.8 | 1.4 | 1.44 | 1.42 | 1.42 | 2.877949238 |
| 1.9 | 1.42 | 1.4 | 1.4 | 1.406667 | 2.806490274 |
| 2 | 1.46 | 1.44 | 1.44 | 1.446667 | 3.038291888 |
| 2.1 | 1.48 | 1.46 | 1.44 | 1.46 | 3.129263666 |
| 2.2 | 1.46 | 1.46 | 1.46 | 1.46 | 3.129263666 |
| 2.3 | 1.48 | 1.44 | 1.46 | 1.46 | 3.129263666 |
| 2.4 | 1.5 | 1.5 | 1.5 | 1.5 | 3.465735903 |
| 2.5 | 1.46 | 1.5 | 1.52 | 1.493333 | 3.401197382 |
| 2.6 | 1.54 | 1.5 | 1.5 | 1.513333 | 3.608836746 |
| 2.7 | 1.5 | 1.54 | 1.52 | 1.52 | 3.688879454 |
| 2.8 | 1.52 | 1.56 | 1.5 | 1.526667 | 3.775890831 |
| 2.9 | 1.52 | 1.6 | 1.52 | 1.546667 | 4.094344562 |
| 3 | 1.58 | 1.5 | 1.54 | 1.54 | 3.976561527 |

Captions.




From the data above we can prove the fact the relation to a certain extent if we ignore the additional term . However, the standard deviation on average is relatively high which can be returned to the instability of the FID signals.The last two values was in order to find the maximum signal or Meq shown in the experiment above.T1 in this experiment is 0.966 s and the theoretical value is about 1.33 s which is considerably near with a difference of 27.3%.(The theoretical values are not accurate as the source in the internet have varying values that some crosseponds exactly with our value and some goes eve to twice its value as there are different calculation method of it!!!!So the value shown is th average).The difference arises when measuring the values from the condition of the used water (temperature,pressure,etc...) and the degree of its purity as our value is for perfect oxygen free water.Also it depend largely on the used magnetic field in these experiment as in our case it is 1.5 T which will alter the results if the used magnet was 3 T.The main source of disturbance is the additional constant which cannot be controlled as the values of the intersection with the origin is away from the distinguishable delay time of the two signals .Another important defecting factor the large instability which itself changes in time in unpredicted way such that we cannot specify equilibrium time or something of this sort.

**Determination of T2**

Then we transferred to T2 which is very hard and I actually I were able to take only 3 terms due to difficulties in the oscilloscope and the appearance o f the Gaussian-like shape of the indtede pulse.The main goal is to find this shape and evaluate it as amplitude which is related as well to magnetization dnis considered equivalent since it effect is removed from the exponential and logarithmic functions .However, we could eventually figure out the general shape and so the value of T2.First of all ,this experiment is governed by similar principle to the last one.The main action here is supplying a 90 dgree pulse then a delay then supply 180 pulse then a delay and then we get the special thing which is the echo.Echo is in the form of a Gaussian shape in this experiment and this one arises from the contribution of several signals.

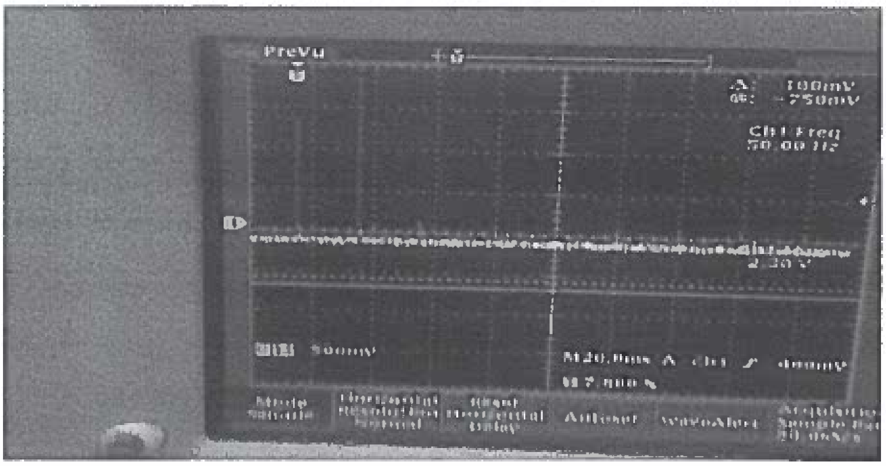
First we supply a 90 pulse rotate the Meq from z-axis to x-y plane.Then the180 flips the magnetization into the other side in the x-y plane.The higher field spins precess in quicker than larmor frequency and so it get out of phase.Another magnetization rotates in lower frequency such that both pulses rephrase at period of 2τ.The produced shape of rephrasing is called the echo and from its we can predict the T2.

The equation describing the phenomena is

$$\ln\left(M_{x,y}(2\tau)\right)=\frac{-2\tau}{T_2}+\ln(M_{eq})$$

Where Meq is the magnetization equilibrium,T2 is spin-spin relaxation time, τ is the delay.

The process of experiment is similar to the first one in several aspects .The difference is only the sequence of the pulses and the number B of pulses.The oscilloscope must be working on large time scale about 20-40 ms.The shape we get of the pulses consists of two large pulses which are form the precessing phases then we get a tiny echo of the Gaussian distribution.We got this shape for the signals .The picture might not be clear but this illustrates the size 0of the time scale used in order to display all of the signals.




The first long faint two lines on the left are the signals and the third small line is the echo signal
There were many signals produced as we increase the delay time and the frequency of the appearance pf the echo reduces which might but that in the delay process more splitting of the frequencies occur.The ultimate reading was the third one where the largest signal was most appearing or actually several signals with very high amplitude and the echo were very hard to detect. Then it submerged in the noise and became impossible to detect .The image shows the data collected and the graph for finding T1.

| τ (ms) | _2τ(s) | M1-1 | M1-2 | M1-3 | AVERAGE | ln(M) |
|---|---|---|---|---|---|---|
| 10 | -0.02 | 0.384 | 0.39 | 0.364 | 0.379333 | -0.96934 |
| 20 | -0.04 | 0.272 | 0.276 | | 0.274 | -1.29463 |
| 30 | -0.06 | 0.168 | 0.17 | | 0.169 | -1.77786 |

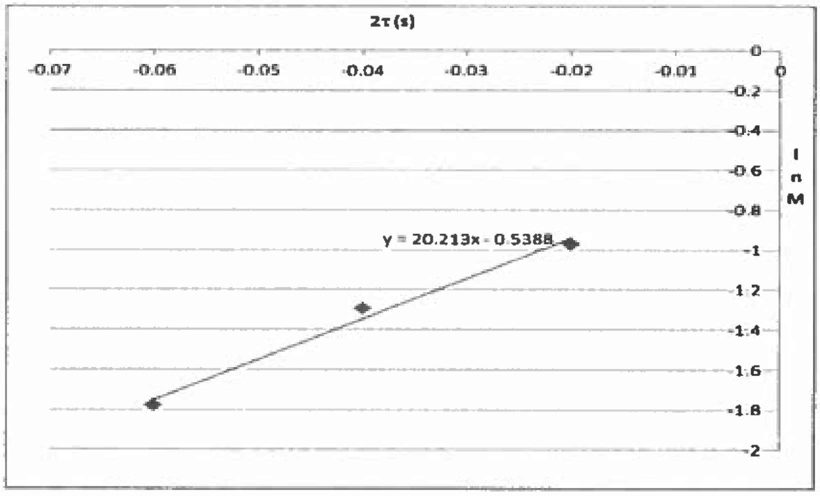
The 

figure above shows the relation between delay time and the lnM.Here the delay time is double beacesu it ois the time taken for the rephrase of the several spin frequencies.The relation seemed linear to a great extent.T2=49.5 ms in the experiment and theoretically is hard to determine as in the internet the values vary very thoroughly to an extent that can not be averaged .For instance, we have for very pure water T2 is 3-4 s and for oil water it is about 20 ms.Thus we cannot determine exactly the T2 form the internet as we are sure that our water is neither very pure nor water oil mixture.Generally the value seems reasonable to a great extent if we compare it with similar tissues (mostly water) as brain white matter (70 ms).Generally, the experiment is hard to implement perfectly as the noise intensifies the echo or removes or simply disturbs it.

## Conclusion

The following data collected for the NMR s extremely important for a lot of nuclear physics and chemistry applications and most importantly in the medical field as it is the backbone of the MRI.This implies its understanding and determination of every property associated with the organic material is very I important especially if these were as important as T1 or T2.The experiment were generally beneficial in the knowledge of the operation of the nmr experiment.The main conclusion form this experiment is understanding the role played by the larmor precession and how the supplied RF signals can play important role in the operation of the larmor precession mechanism in the nucleus itself rather than in the atom.

# OPTICAL PUMPING

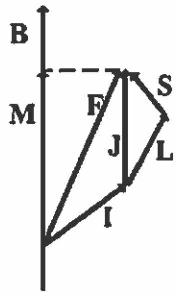
**Objectives**

The objectives of this experiment are mainly to investigate the effectiveness of the proposed theory through investigating the quality of the signal .Then we investigate between the temperature and the signal and also the frequency with the signal under certain conditions.

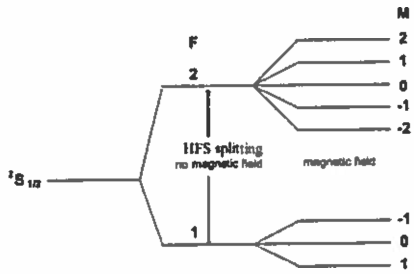
**Introduction**

The main physical process behind all of this experiment involves the relation between magnetic field and the frequency of the signal produced which represents the portion of light slowed to pass.The isotopes used are Rb 85 and Rb 87 which have the same outer electron configuration as the hydrogen atom .The single valence electron have an angular orbital and spin momentum which both add up to the magnetic components J from L and S in the form .(Fine Splitting)


This component will also add to the nuclear orbital moment which will give us the hyperfine splitting which plays similar role with the angular and spin momentum as shown above.



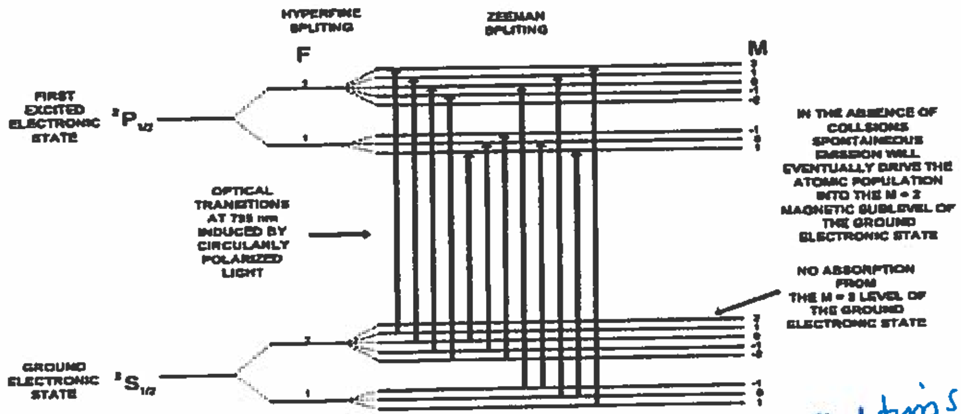

This phenomena happens on different energy levels in the atom which leads to further splitting of the electron level configurations into certain energy levels as shown below.This figure below demonstrates the effect on the electron levels of typical atom when a magnetic field is applied.The splitting includes the orbital and nuclear splitting and also another splitting due to the magnetic field.




caption ?

The splitting processes in the orbital structure of the energy states due to external magnetic fields are called zemann effect.At these energy states what happens is that the electron itself will excite when subjected to a photon or spontaneously into a higher level guide by certain selection rules.Then the decay back into their ground state based also on certain section rules.This process will certainly emit photons with certain frequencies based of the energy gap.Some transitions emits visible photons .This figure below demonstrates these transitions.

mention the selection rule!




captions ? ?

Note that the mentioned properties of splitting and excitation and Zeeman effect is very observable and practically effective only for certain elements or even isotopes even though that if occur in all atoms.For example orbital splitting is mainly observed in single valence.

The excitation and decay are continuously occurring following the selection rule till reaching finally the saturation level or the dead lock level.Form here, we can start deriving our experiment basic idea.If we disturb this dead lock position sufficiently it will lead to other distribution and so there will be photons emitted till reaching the same dead lock till reaching the position after a certain period of time.These emissions will produce a certain signal on our oscilloscope.

Not clear

From the main quantities we are interested in the experiment is the gyromagnetic ratio as it acts as an indication of the successes of our experiment and more importantly i9t guides these processes of emissions and the speed of collapse of the electron energy states. Gyromagnetic ratio is a quantum quantitiy that determines the responsiveness of the frequency on changing the external magnetic field.

$$\omega_0 = 2\pi\nu_0 = g_f \frac{\mu_0}{h} B_0$$

Where wo is the frequency precession,μo is the magnetic moment,h is the planck momentum and Bo is the external magnetic field and gf is the gyromagnetic number.

Gyromagnetic ratio is

$$\gamma = g_f \frac{\mu_0}{h}$$

The optical pumping relies prominently on the relation between the emitted photon and the magnetic fields whether from earth or internally or from the 3 coils we are having.These coils represent vertical, horizontal and internal modulator of the magnetic field.The spectrum produced by some of the isotopes is very characteristic under the presence of the magnetic field which will be altered under any change in the magnetic fields.The intensity of the light emitted by the sample is governed by certain conditions as temperature and stability of the electron levels and the time they take to return to the dead lock position.

The used samples are in the gaseous form .The light is used to control the energy states in the electron and to so to alter the emissions of the sample.The relation between the different sates is normally guided in the absence of light by this formula:

$$\frac{n_B}{n_A} = \exp\left(-\frac{E_B - E_A}{k_B T}\right)$$

Where n's are the energy states,E's are the associated energy and k is the Boltzmann constant.

On the application of external light the magnetic numbers ml are disturbed which will then lead to the emission of light.The light must be polarized in order to produce the light in a certain direction on the vertical and horizontal axis which in place will make the gas polarized.

The role of the magnetic resonance in this experiment is very important and it quantizes our various factors. The applied magnetic resonance is in direction perpendicular to the polarization of the gas.if the magnetic field is sufficient to change magnetization then its frequency must be

$$\nu = \frac{g_F \mu_B B}{h}.$$

Where B is the magnetic field,h is planck's constant ,gf is gyromagetic factor and μB is the bohr magneton.

When the magnetic field reaches the RF region then the intensity of absorption will increase since the two states are in equilibrium which in place will decrease the transmitted light intensity.The intensity of the transmitted light is related with the density of the gas in the following relation:

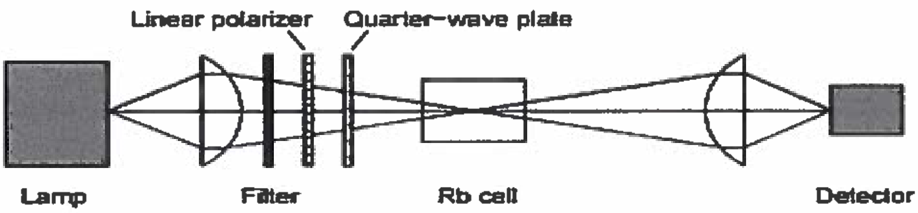
$$I = I_0 e^{-\sigma \rho x}.$$

I is the transmitted light intensity ,Io is the initial intensity ,σ is the cross section,x is the path length and ρ is the density of the gas.

Also as the magnetic field increases there will be  more positions for the electron thus there be less photon absorption thus it will lead to an increased transmitted light intensity .

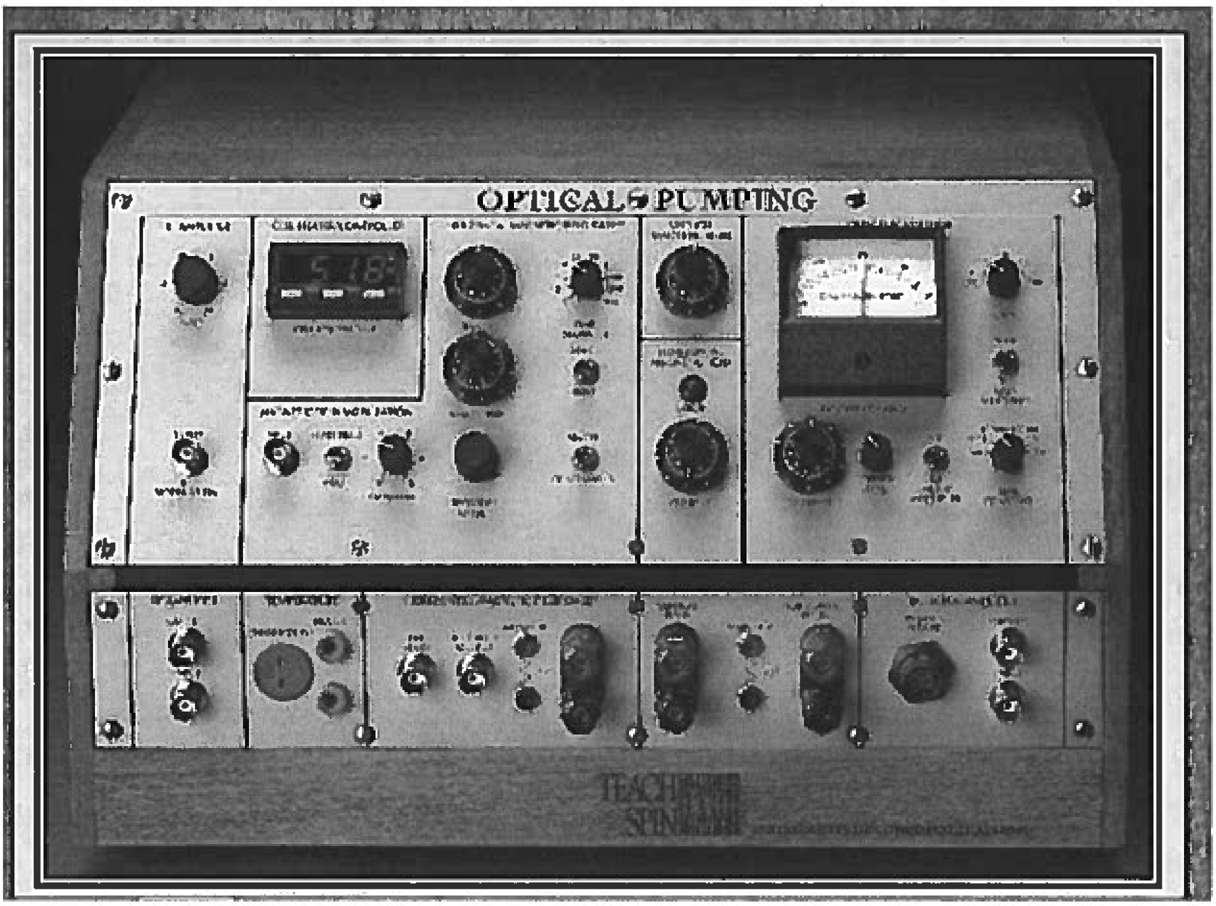
**Apparatus**

The main apparatus in our experiment is demonstrated in the figure below:




- Lamp emits the Rb light at a resonant frequency or the best energy for optimal absorption by the sample
- Lenses are used to guide the light path for converging or diverging
- Linear Polarizer is used for the control of the plane and make in a certain axis linearly which is necessary for the circular polarization
- Quarter Wave Plate is used to polarize the light to be in a circular polarization which was in our case right circular polarized.This is essential for the process of optical pumping in Rb.
- Rb cell is the major part in this experiment as we will have in it the applied the magnetic fields and the Rb sample
- Detector which measures the intensity of the photons emitted by the sample and the allowed original light beam. However, most of the photon is from the lamp originally.
- Filter is used to filter the light from sates higher than $S^{1/2}$ and $P^{1/2}$ which is very important for limiting the transition I the atom and also to reduce the range of the stable positons in the electron levels.

This is the detector and the controller for the magnetic fields and the temperature .It includes also a galvanometer from the current coming from the detector.Actually, this device completes the circuit for a representation in the oscilloscope and the opposite.Moreover, the RF frequency supplier is also connected to this circuits.Here we also have temperature detector and regulator which is essential and time consuming process .The figure below shows the apparatus we used.




**Experiment and Data Analysis**

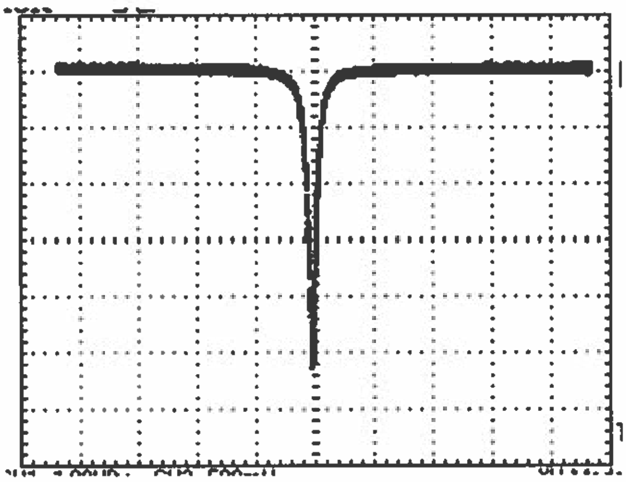
The most basic step yet important step is the temperature regulation and setting the proper temperature .This process take about 20-30 minutes.This is mainly due to the volatility of the electron states and the volatility of the Rubidium isotopes used (Rb 85 and Rb 87).This is done by the temperature regulator .The optimum temperature or the most used one is 50C due to various chemical and physical properties of the rubidium isotope.We vary it later in the first experiment but in the setup we sue this temperature.

Another important point is that this experiment is very sensitive to any changes in the magnetic field and the position (related to earth magnetic field).This also implies that our magnetic fields depends on the geographical position.Another aspect is also the magnetic materials as mobiles,keys and other daily tools.Moreover, the stability was very tedious for the table especially in the positioning of the optics.

Another huge challenge was the effect of external lighter readings which was also defecting our readings and required us to use two blankets in order to cover the setup completely and still the results were not as desired at some stages.

The setup of the optics was the most important part as they must be exactly in the proper vertical distance from the axis and in the same time it must coincide with the lenses distance from the lamp and the detectors .More importantly is that we get our focal point in the center of the sample or near this position in order to maximize the signal.This is crucial for the later experiments .Then comes the process of acquirement to of the zero field transiton .

The acquirement of the zero field transition is axial and hard to obtain in the same time.What happens is that we must first neglect or delete the magnetic field vertical component .Then we tend to find the zero dip that is shown in this figure.

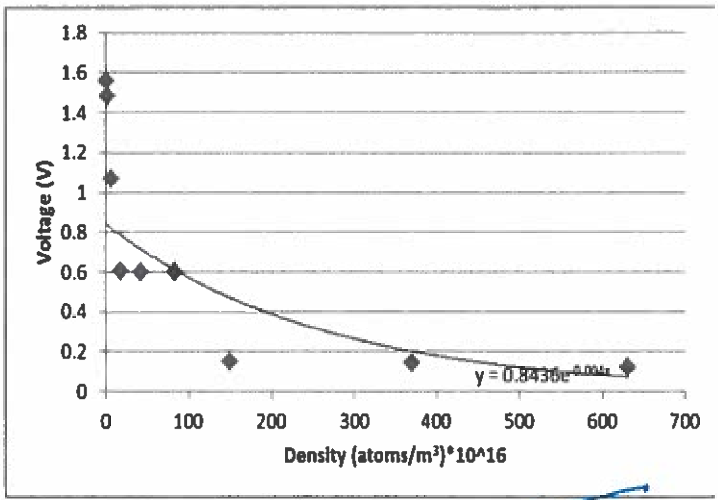


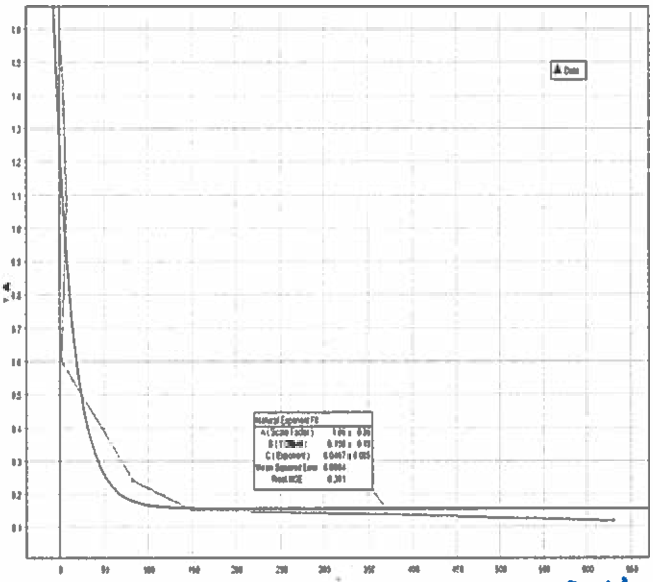
This is done by changing the sweep magnetic field (the one associated in the coil) till getting this figure.However, in the same time the offset current must be kept zero at the galvanometer .After getting this data then we set our magnetic sets from the first experiments at these values and we start the experiment.

**Experiment 1 Absorption cross section of the Rb sample**

First we must remove the polarizers in this experiment as they will not be needed and the temperature regulator must be turned off at a temperature of 300K and allowed to gain equilibrium .Then we try to vary the temperature and notice the rms for our signal in the oscilloscope .This is an indication of the permittivity of the Rb sample which leads directly to the concept of the cross section which is very important in relating the temperature with the stability and the optical pumping phenomena in the Rb isotopes. Obviously this experiment is one while keeping the horizontal and vertical magnetic field zero and the sweep field at the zero transition value.We repeat this experiment for 10 K increments in order to determine the cross section value and compare it with the theoretical value.Notice that we keep all the magnetic fields and current untouchable in these experiments .The table and below shows us the data we obtained.

| Density | Intensity |
|---|---|
| 1.10 | 1.56 |
| 2.90 | 1.48 |
| 7.50 | 1.07 |
| 18 | 0.605 |
| 43 | 0.6 |
| 83 | 0.6 |
| 150 | 0.15 |
| 370 | 0.14 |
| 630 | 0.12 |



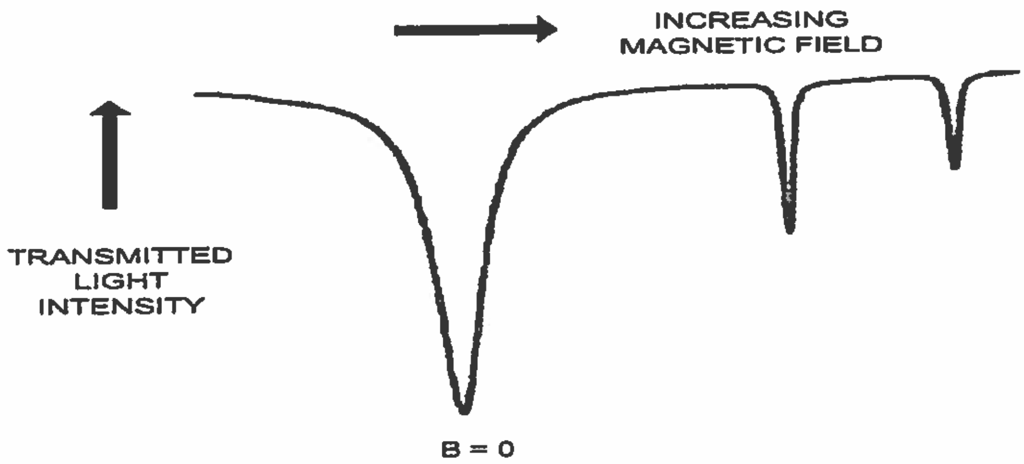



The table of data above was analysed in two different programs (excel and Sigma).However, excel curve was not suitable for these type of data thus I depended entirely on the Sigma plot readings.The results give me A to be 1.06 and σ is 0.0457.The expected readings for A is t.36 and for σ is 0.04.These values might seem ok but not perfect due to various factors.The first one is the hard time with getting the zero field transition which its absence lead to repetition of the experiment under varying conditions till getting the zero field and these set of readings but with les range.So the readings are heterogeneous for honesty.Second thing was that the temperature stability took a lot of time that sometimes I omit.From the values of A and σ we can get specific cross section from the path which is $\sigma_o$=0.0457/0.025=1.83E-16.The expected value is 1.60 E-16 so the error is 12.6%.This cross section means the absorption which is dependent as we saw on the temperature implicitly in the form of the density based on an exponential curve.The voltage was used in place of the intensity due to the direct proportionality between them.We used the rms is crucial as it takes a more realistic approach.Another important aspect is the effectiveness of the change in temperature depends massively on the value of the magnetic field that could shift the values in a great manner.Also we can see that the change decreases as we increase the temperature and the relation get saturated at higher temperature which makes a bit fi sense in terms of thermodynamics.

**Experiment 2: Low Field Resonances**

In this experiment we relied mainly on RF pulses in order to extract various information about the nature of the behaviour of the sample and the signal.First we used the polarizers as we will inspect a process in a direct link with the optical pumping and its relation with frequencies and magnetic fields.The temperature was set at 320 K which as mentioned previously have huge importance for our sample.In this experiment we dealt with the components of the sample rather 6than then whole mixture and we could be able to differentiate between Rb 85 and Rb 87.Ofcourse first we made shore that we are at the zero magnetic resonance.Then we work for finding the gyromagnetic factor which as discussed earlier fundamental in the determination of the various electron states behavior in the Rubidium isotopes.Here there will be application of radiofrequency in the device and notice the corresponding effect on the zero transitions .

First we found the magnetic residual fields 0.2884 T.Then we applied the RF frequency coils.We found qualitative change and quantities change in the two displays in the oscilloscope .What we must get when sweeping the magnetic field slowly get these three transitions:




For the first dip what happens is that the magnetic field cancels the horizontal earth magnetic field which cases the splitting.So at the zero field the energy states collapse to their fine hyper splitting structure so the absorption will increase of the photons which I will reduce the transmitted light.As we sweep the current more the signal increase as we now caused the splitting by this applied magnetic field to the original excited states for the electron .Then here comes the cancellation of the splitting of the nuclear magnetic field which is opposed by the external magnetic field and thus here the dip occurs due to the

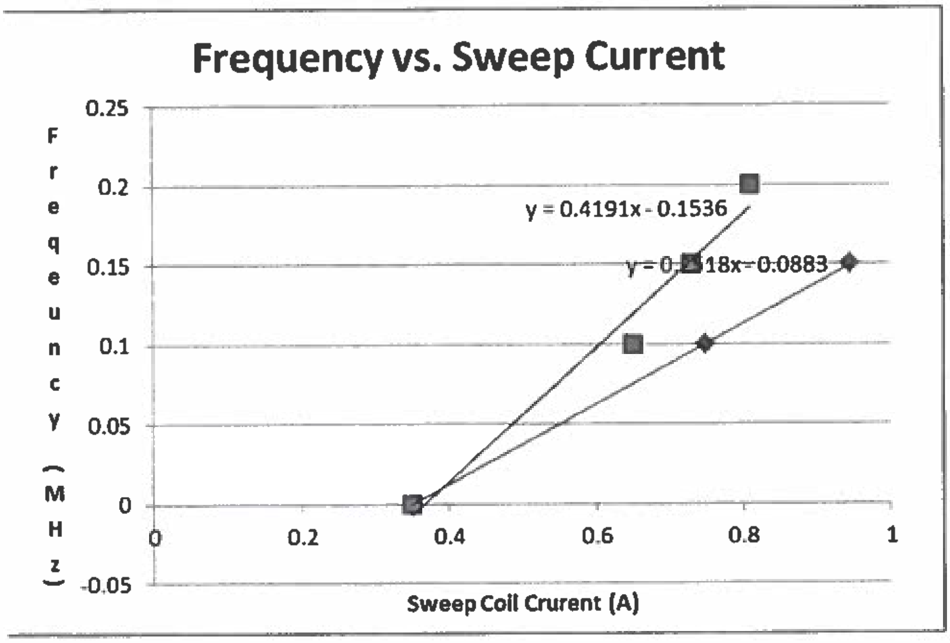
V. good

same reason explained earlier.We are expected to notice or actually we noticed two dips due to the repetition of the phenomena with the two isotopes in the sample Rb 85 and Rb 87.

These two dips currents are dependent on the frequency used from the RF coil.Actually the two dips cannot be obtained without the use of transition frequencies from the RF coils due to the nature of the nuclear magnetic field.

The results we got on sweeping the magnetic field in the RF frequency application Was similar to these values for the first and second and third dip.Of course the offset current was maintained to be at zero.There were a slight difference on the relative sizes of the small two dips. Another point was on sweeping the magnetic field below the zero field transition value we got the same dips in corresponding positons to the right forming symmetric shape which indicates that also o0n increasing the sweep current on that side there is also a similar phenomenon occurring which will be discussed in moments. The results we got are illustrated in the table below.

| Frequency (MHz) | current Rb 85 (A) | current Rb 87 (A) |
|---|---|---|
| 0 | 0.35 | 0.35 |
| 0.1 | 0.65 | 0.75 |
| 0.15 | 0.73 | 0.945 |
| 0.2 | 0.81 | |




Red dots resembles the curve associated with Rb 85 and the blue ones are associated with Rb 87.The results are similar to the expected.What happens at the 3 dips is different for each case.The magnetic field starts for both of the isotope obviously the same at B=0.35 T.We used then the frequencies of 100 kHz because it is the minimum possible frequency.When putting the display we get the transitions at these sweep coil currents.These values looks pretty identical to the ones in the manual but this can be verified only by computing the gyromagnetic factor which is known by taking the quotient of the Rb 85 /Rb 87 slopes .We get the gyromagnetic factor to be equal to 1.544 while the theoretical value is 1.5.We get an error of 3% which is very reasonable and excellent in comparison of the first experiment results.These results illustrates the linear relation of the magnetic field with the frequency which is illustrated earlier in the theory part.Rb 87 have less readings because that the value corresponding to 200 kHz is out of the range but it can be approximated by the linear relationship .Another important point is the stability of the zero field transition in magnificent way with the frequency which asserts the fact that the zero field transition is independent from the frequency of the applied RF signal.In this process we test the validity of the magnetic resonance phenomena explained in the theory part by finding the gf values and compare it with the theortical.Actaully, the maximum value and the best one to notice these 3 dips clearly is at 150kHz but not necessarily with the same of order of sizes.Another interesting observation were the saw teeth signals in the direct display of the waves.(Showing the signal as function of time)At these we notice that at 100 khz frequency we have a saw teeth signals which vary and get their sharpening at values near to the magnetic dips surprisingly (0.383,0,643,0.80)A.This seems to be another way to find the display seeing the signals themselves.Yet on sweeping the current the amplitude decreases in its amplitude linearly.

**Conclusion**

This experiments is a direct implication of the phenomena of the quantization and Zeeman effect from the electron and nuclear spin which is a bit new in comparison with the usual electron resonance phenomena we are used to deal with.The two main information about the relation with the stability magnetic field and the magnetic resonance.The first important result is that the temperature and the intensity are inversely related with each other especially that the relation is decreasing exponential .Another important result is verification of the theory that asserts of that the magnetic field is directly proportional with the frequency of the precession that was controlled by the Rf signal in the coil.Another implicit points were the independent of the zero magnetic field with the frequency and the other important of the earth magnetic field and magnetic fields form in the atom or out of it.However, the most important fact verified is the optical pumping phenomena itself which was illustrated in the variance of the transmitted light (our signals) with the external factors. Also the fact of using the same isotopes for the photon emission and the absorption would strengthen the existence of this process since these samples are of the same type so will have no chemical or other interactions.

# X-RAY DIFFRACTION

**Objectives**

This experiment is mainly a mixture of heterogeneous ideas about the x-ray behavior by utilizing the x-ray diffractometer available to investigate their validity.First we will investigate the process of Bragg reflection and its dependence on the angle.Then we will analyze the x-ray spectrum in terms of its dependence on the potential and emission current.Then the relation between the potential and the angle and the wavelength from where we will determine the planck's constant.Finally,we will test on the attenuation as related to the material used and related and the thickness of a single chosen.

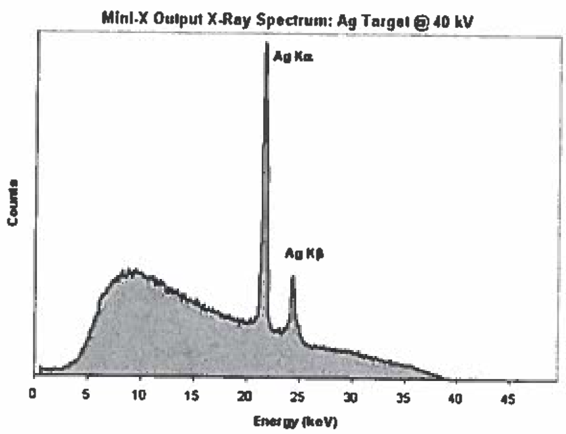
## Introduction

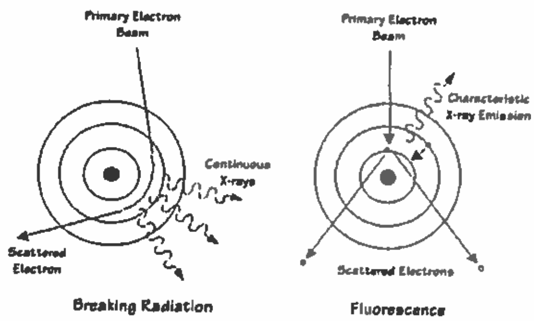
First let's give brief information about the x-ray and the x-ray diffractometer and its basic functions and us.

**X-Ray**

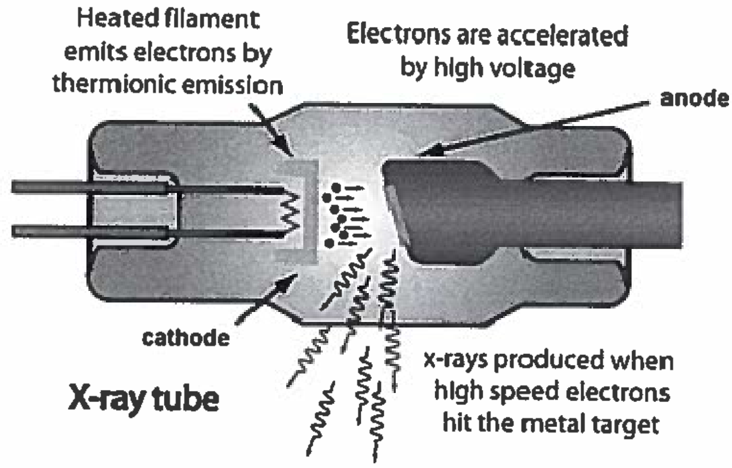
X-ray resembles a type of electromagnetic radiation of high energy which is produced due to the transitions in the electron energy shells of high .The energy of X-rays are usually high enough to ionize the atom.The difference between the gamma and X –rays are mainly from the source of production more than the energy factor.

There are two types of X-ray radiation: characteristic and general. Characteristic are the ones produced from the changes in orbital levels in the atom which is quantized to occur at certain values and thus forming a spectrum .There is also the general radiation that comes when a free electron gets attracted to certain nucleus which casus a loss of energy of the photon which in turn will lead to the production of x-rays .This x-rays can be produced and emitted at any energy level (not discrete).Thus the majority of the x-ray beams are produced in this from .The figure explains illustrates these facts for the case of silver isotope.



X-ray Production




The production of x-ray is a complex procedure technically but the basic production is fairly simple.As shown in the figure above. First the filament, usually made of tungsten, is heated in order to produce electrons by thermionic emission due to the applied voltage. Then these electrons are accelerated by another voltage difference from negative to positive electric plates till reaching the sample.Then it hits the sample which is usually from carbon or metallic.This sample is inclined at an angle of 45 which is necessary for physical (compton effect) and geometrical reasons .The x-ray is produced due to the Compton effect.

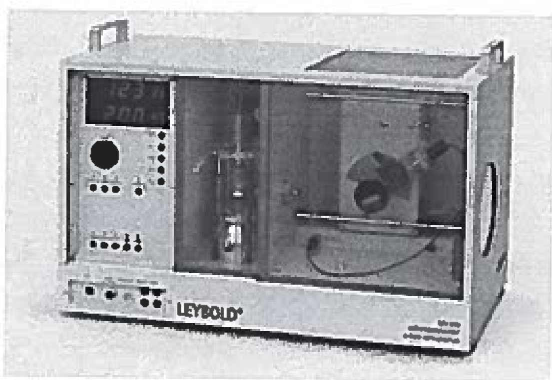
This is scientifically wrong! The accel^n stops much before it reaching to the sample.

X-Ray Diffractometer

The X-Ray undergoes diffraction as the case of the visible light.This process is governed by similar laws.This process is used in the x-ray diffractometer in order to analyze the structure of the crystals.

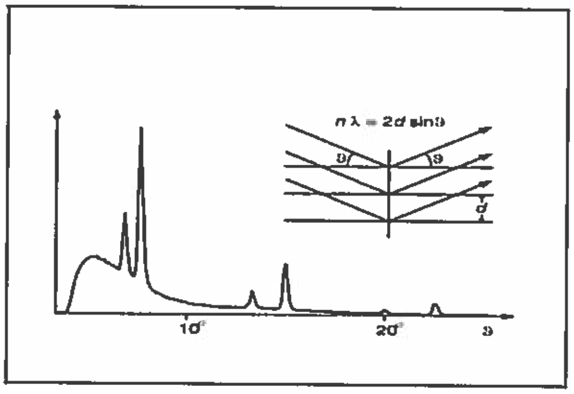
language is not clear.

For our device the used one is




Bragg's law

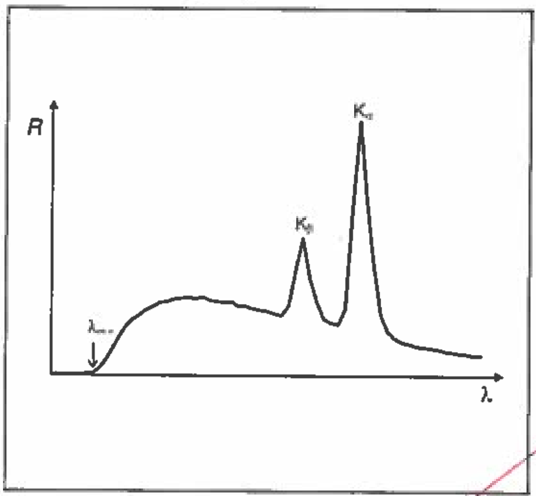
The is the law governing the diffraction that the x-ray photon undergo in the crystal structure of parallel layers .This process is fundemantal process of the x-ray crystallography. Bragg reflection where the external photons undergo reflection from the surface with a certain path difference between then the adjacent layers .The idea is more explained in the following experiment.




X-ray Powder Diffraction (XRD)

This technique uses the above processes I order to find the crystalline structure and its properties where the sample is presented as fine powder to improve the analysis.The diffracted light is detected for all the angles in a certain range of angle.Each spectrum crossponds to a fundamental elemnt at a certain angle obiuvsly and free here we can determine our content in percentages or ratios.

Determination of Planck's constant




We have that limit wavelength is inversely proportional of the potential.

$$\lambda_{min} = \frac{h \cdot c}{e} \cdot \frac{1}{U}$$

Where h is the Planck's constant ,c is the speed of light , e is the electron change and U is the potential.So the limit wavelength corresponds s to the maxi um frequency and so energy.

**Attenuation of X-rays**

X-rays as any photons or particles get absorbed or reduced in the beam intensity when it passes through any material .This attenuation in most of the takes the form of exponential decrease.This decrease happen mainly due to two processes scattering and absorption .Absorption is the domination process. The attenuation of depends on the substance thickness and on the material type which will be our experiments later on.For the case of the thickness we have the following relation:

$$T = e^{-\mu \cdot x}$$

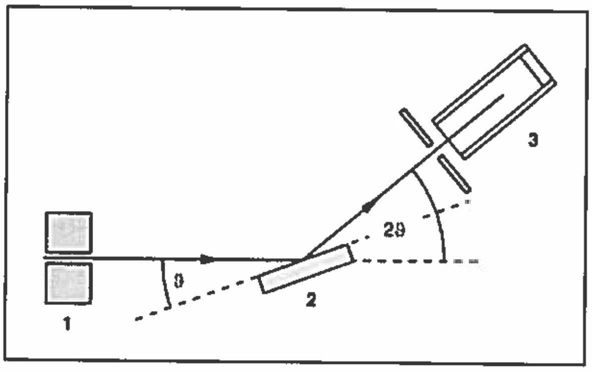
where T is the transmittance ,μ is the attenuation coefficient and x is the thickness.

## Experiments

Before starting experiment we make sure that the setup is in the appropriate position such that we get the best possible results.Then we put our sample on the target holder and mount it carefully .We will use this sample (NaCl crystal) for the first three experiment .Apart from the first experiment the order of reflection wavelength will be 1 which should explain the appearance of one characteristic peak pair.

**Bragg Reflection**

In this experiment we tested for the occurrence of Bragg reflection which is the most fundamental process for the XRD machine .This was performed by the variance of the angle for certain potential and currents for the X-ray.The setup was as the following:




Where at 1 the ray is straight then we have deflection from the plate with t he same angle with nomral of incident.The angle we are changing is the glancing angle $\vartheta$ gradually.Then when the x-ray hits the plat at this angle it will be detected by the detector.The mechanism is fairly simple.We get later on the following results for V=35 kV and I=1 mA and values of $\vartheta$ from 2 to 25 with $\Delta\,\vartheta = 0.1° for\ \Delta t = 10s$ .

| &b / ° | R_0 / 1/s |
|---|---|
| 2 | 15.8 |
| 2.1 | 15 |
| 2.2 | 2 |
| 2.3 | 14 |
| 2.4 | 13.9 |
| 2.5 | 13.7 |
| 2.6 | 12.6 |
| 2.7 | 11.7 |
| 2.8 | 13.9 |
| 2.9 | 13.3 |
| 3 | 15.2 |
| 3.1 | 14.9 |
| 3.2 | 16.8 |
| 3.3 | 20.3 |
| 3.4 | 42.5 |
| 3.5 | 162.2 |
| 3.6 | 343.7 |
| 3.7 | 517.9 |
| 3.8 | 637.4 |
| 3.9 | 737 |
| 4 | 816.1 |
| 4.1 | 895.8 |
| 4.2 | 924.5 |
| 4.3 | 980.9 |
| 4.4 | 995.3 |
| 4.5 | 1014.4 |
| 4.6 | 1025.5 |
| 4.7 | 1025.9 |
| 4.8 | 1014.9 |
| 4.9 | 1016.4 |
| 5 | 1011.8 |
| 5.1 | 1004.1 |
| 5.2 | 972.2 |
| 5.3 | 946.1 |
| 5.4 | 933 |
| 5.5 | 904.3 |
| 5.6 | 843.5 |
| 5.7 | 835.8 |
| 5.8 | 803.7 |
| 5.9 | 782.5 |

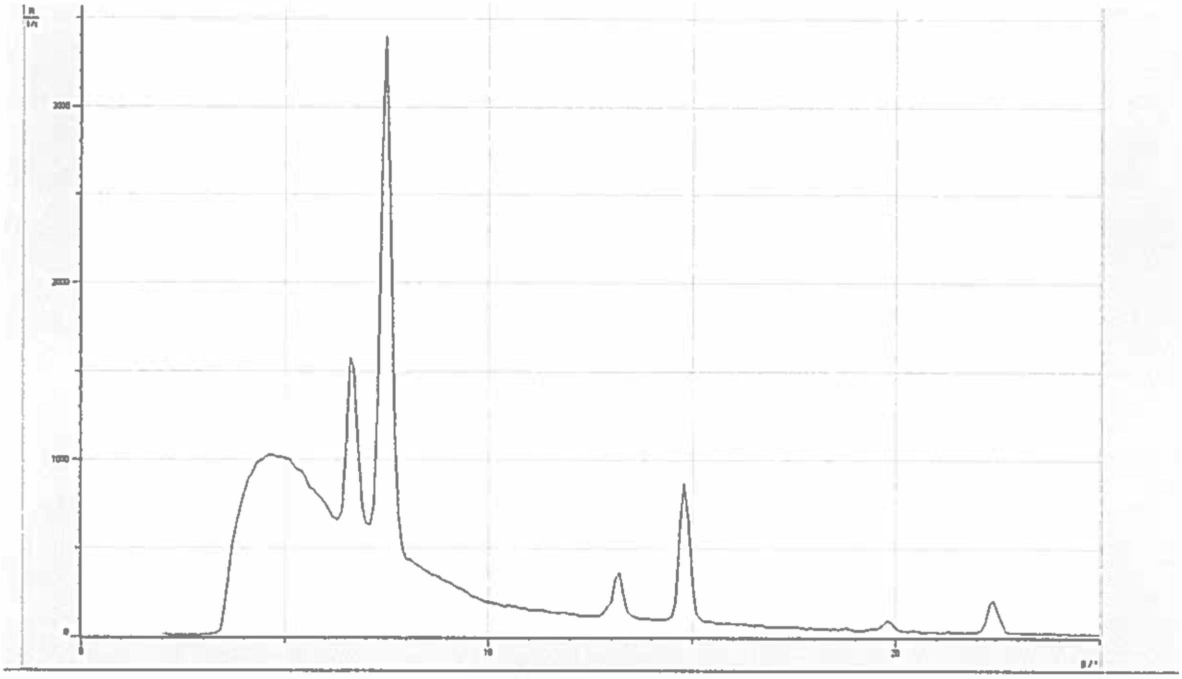
| | |
|---|---|
| 6 | 751.7 |
| 6.1 | 710.3 |
| 6.2 | 671.9 |
| 6.3 | 660.3 |
| 6.4 | 715.2 |
| 6.5 | 1051.6 |
| 6.6 | 1577.3 |
| 6.7 | 1518.1 |
| 6.8 | 1069 |
| 6.9 | 734.9 |
| 7 | 646 |
| 7.1 | 631.9 |
| 7.2 | 746.3 |
| 7.3 | 1359.2 |
| 7.4 | 2749.6 |
| 7.5 | 3395.7 |
| 7.6 | 2465.8 |
| 7.7 | 1165.8 |
| 7.8 | 698.5 |
| 7.9 | 498.7 |
| 8 | 440.5 |
| 8.1 | 436.5 |
| 8.2 | 412.9 |
| 8.3 | 404 |
| 8.4 | 382.8 |
| 8.5 | 371.9 |
| 8.6 | 354 |
| 8.7 | 347.8 |
| 8.8 | 336.5 |
| 8.9 | 320.2 |
| 9 | 312.2 |
| 9.1 | 303.4 |
| 9.2 | 282 |
| 9.3 | 274.8 |
| 9.4 | 262.9 |
| 9.5 | 251.1 |
| 9.6 | 229.6 |
| 9.7 | 224.9 |
| 9.8 | 214.1 |
| 9.9 | 203.1 |
| 10 | 195.2 |

| | |
|---|---|
| 10.1 | 191.7 |
| 10.2 | 190.3 |
| 10.3 | 181.8 |
| 10.4 | 173.1 |
| 10.5 | 182.6 |
| 10.6 | 174.1 |
| 10.7 | 172.1 |
| 10.8 | 161.1 |
| 10.9 | 163.2 |
| 11 | 153.6 |
| 11.1 | 153.3 |
| 11.2 | 152.7 |
| 11.3 | 151.1 |
| 11.4 | 149.2 |
| 11.5 | 140.9 |
| 11.6 | 139.6 |
| 11.7 | 135.1 |
| 11.8 | 139.8 |
| 11.9 | 139.7 |
| 12 | 126.8 |
| 12.1 | 129.5 |
| 12.2 | 124.3 |
| 12.3 | 118.7 |
| 12.4 | 121.3 |
| 12.5 | 118.5 |
| 12.6 | 117.7 |
| 12.7 | 117.7 |
| 12.8 | 135.3 |
| 12.9 | 172 |
| 13 | 198.5 |
| 13.1 | 330.2 |
| 13.2 | 364.2 |
| 13.3 | 254.8 |
| 13.4 | 146.7 |
| 13.5 | 122.7 |
| 13.6 | 116.6 |
| 13.7 | 107.9 |
| 13.8 | 108 |
| 13.9 | 106.5 |
| 14 | 104.7 |
| 14.1 | 101.9 |

| | |
|---|---|
| 14.2 | 104.7 |
| 14.3 | 101.9 |
| 14.4 | 101.1 |
| 14.5 | 117.8 |
| 14.6 | 206 |
| 14.7 | 644.2 |
| 14.8 | 871.8 |
| 14.9 | 655 |
| 15 | 314.3 |
| 15.1 | 136.5 |
| 15.2 | 108 |
| 15.3 | 88.9 |
| 15.4 | 89 |
| 15.5 | 88.7 |
| 15.6 | 77.7 |
| 15.7 | 82.9 |
| 15.8 | 78.8 |
| 15.9 | 83 |
| 16 | 77.2 |
| 16.1 | 77.3 |
| 16.2 | 78.6 |
| 16.3 | 72.1 |
| 16.4 | 69 |
| 16.5 | 67.2 |
| 16.6 | 71.2 |
| 16.7 | 68.8 |
| 16.8 | 63.3 |
| 16.9 | 58.7 |
| 17 | 61.4 |
| 17.1 | 62.9 |
| 17.2 | 59.1 |
| 17.3 | 58.2 |
| 17.4 | 57.6 |
| 17.5 | 60 |
| 17.6 | 58.6 |
| 17.7 | 55.2 |
| 17.8 | 51.3 |
| 17.9 | 57 |
| 18 | 47.2 |
| 18.1 | 48.7 |
| 18.2 | 50 |

| | |
|---|---|
| 18.3 | 48.7 |
| 18.4 | 44.9 |
| 18.5 | 49.3 |
| 18.6 | 43.9 |
| 18.7 | 48.8 |
| 18.8 | 51.6 |
| 18.9 | 47 |
| 19 | 41.6 |
| 19.1 | 43 |
| 19.2 | 43.1 |
| 19.3 | 46.7 |
| 19.4 | 49.3 |
| 19.5 | 49.3 |
| 19.6 | 53.3 |
| 19.7 | 73.3 |
| 19.8 | 98.2 |
| 19.9 | 85.4 |
| 20 | 58.7 |
| 20.1 | 42.6 |
| 20.2 | 37 |
| 20.3 | 37.6 |
| 20.4 | 35.9 |
| 20.5 | 40 |
| 20.6 | 34.6 |
| 20.7 | 30.4 |
| 20.8 | 33.7 |
| 20.9 | 34 |
| 21 | 31.7 |
| 21.1 | 30.2 |
| 21.2 | 30.2 |
| 21.3 | 36.8 |
| 21.4 | 30.8 |
| 21.5 | 33.4 |
| 21.6 | 33.7 |
| 21.7 | 30.3 |
| 21.8 | 34.1 |
| 21.9 | 34.1 |
| 22 | 34.6 |
| 22.1 | 41 |
| 22.2 | 83.7 |
| 22.3 | 187.8 |

| | |
|---|---|
| 22.4 | 212.8 |
| 22.5 | 144.8 |
| 22.6 | 84.1 |
| 22.7 | 37.7 |
| 22.8 | 29.8 |
| 22.9 | 28.6 |
| 23 | 30.2 |
| 23.1 | 29.9 |
| 23.2 | 25.5 |
| 23.3 | 26.7 |
| 23.4 | 25.7 |
| 23.5 | 24 |
| 23.6 | 23.7 |
| 23.7 | 23.1 |
| 23.8 | 24.6 |
| 23.9 | 25.5 |
| 24 | 20.1 |
| 24.1 | 25.4 |
| 24.2 | 26.4 |
| 24.3 | 21.4 |
| 24.4 | 21.6 |
| 24.5 | 22 |
| 24.6 | 24.2 |
| 24.7 | 19.3 |
| 24.8 | 19.7 |
| 24.9 | 19.6 |
| 25 | 20.4 |



As you can see from the figure that we have 3 peaks in pairs where one is always larger than the other.These peaks as explained earlier corresponds to the characteristic X-rays which happens at certain angles.The highest is Kα and Kβ is for the lowest.The peaks occurred at the following values where n represents the number of the peak from left to right.

| n | ϑ(Kα) | λ(Kα)(pm) |
|---|---|---|
| 1 | 7.5 | 73.6 |
| 2 | 14.8 | 72.0 |
| 3 | 22.3 | 71.3 |

| n | ϑ(Kβ) | λ(Kβ)(pm) |
|---|---|---|
| 1 | 6.6 | 64.8 |
| 2 | 13.2 | 64.4 |
| 3 | 19.8 | 63.7 |

Mean λ(Kα)=72.3 pm, Mean λ(Kβ)=64.3 pm

The expected values for λ(Kα)=72.3pm & λ(Kβ)=64.3 pm.The standard deviation for λ(Kα)= 1.18& λ(Kβ)=0.557.Regarding the general appearance of the curve it is obviously the same as the expected one which reflects that the standard for this type of material was good for Bragg Reflection.These results shows three peaks since the characteristic peaks coincide to happen three time from the width of the crystal distance(d=282.01 pm).For the quantities treatment, the deviation of λ(Kα) =1.7 %and for λ(Kβ)= 1.88% which are small quantities that can be usually ignored.

Don't write % error in language
Show it!

**Analyzing of Energy spectrum of x-ray**

In this experiment we are supposed to link between the changing in voltage and the change in current for the energy spectrum we got. We perform the experiment is a straightforward manner that involved only changing the current or voltage and then rescanning for all angle in the scale of each potential value.We got the following results.

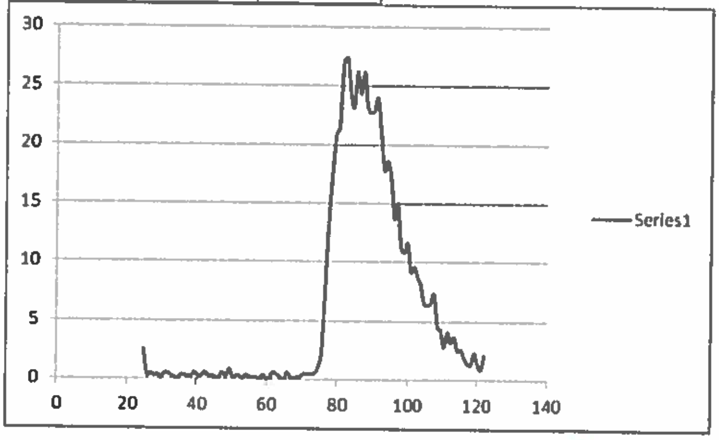
a) V=15 kV

write Beta. nλ?

| &b /° | n&l / pm | R_0 / 1/s |
|---|---|---|
| 2.5 | 24.6 | 2.5 |
| 2.6 | 25.6 | 0.3 |
| 2.7 | 26.6 | 0.5 |
| 2.8 | 27.6 | 0.3 |
| 2.9 | 28.5 | 0.4 |
| 3 | 29.5 | 0.1 |
| 3.1 | 30.5 | 0.5 |
| 3.2 | 31.5 | 0.5 |
| 3.3 | 32.5 | 0.3 |
| 3.4 | 33.4 | 0.2 |
| 3.5 | 34.4 | 0 |
| 3.6 | 35.4 | 0.4 |
| 3.7 | 36.4 | 0.3 |
| 3.8 | 37.4 | 0.3 |
| 3.9 | 38.4 | 0.2 |
| 4 | 39.3 | 0.6 |
| 4.1 | 40.3 | 0.3 |
| 4.2 | 41.3 | 0.3 |
| 4.3 | 42.3 | 0.6 |
| 4.4 | 43.3 | 0.3 |
| 4.5 | 44.3 | 0.3 |
| 4.6 | 45.2 | 0.2 |
| 4.7 | 46.2 | 0.1 |
| 4.8 | 47.2 | 0.6 |
| 4.9 | 48.2 | 0.2 |
| 5 | 49.2 | 0.9 |
| 5.1 | 50.1 | 0.2 |
| 5.2 | 51.1 | 0.3 |
| 5.3 | 52.1 | 0.3 |
| 5.4 | 53.1 | 0.1 |

| | | |
|---|---|---|
| 5.5 | 54.1 | 0.4 |
| 5.6 | 55 | 0.2 |
| 5.7 | 56 | 0.2 |
| 5.8 | 57 | 0.2 |
| 5.9 | 58 | 0 |
| 6 | 59 | 0.4 |
| 6.1 | 59.9 | 0 |
| 6.2 | 60.9 | 0.2 |
| 6.3 | 61.9 | 0.6 |
| 6.4 | 62.9 | 0.4 |
| 6.5 | 63.8 | 0.2 |
| 6.6 | 64.8 | 0 |
| 6.7 | 65.8 | 0.6 |
| 6.8 | 66.8 | 0.2 |
| 6.9 | 67.8 | 0.1 |
| 7 | 68.7 | 0.2 |
| 7.1 | 69.7 | 0.3 |
| 7.2 | 70.7 | 0.5 |
| 7.3 | 71.7 | 0.4 |
| 7.4 | 72.6 | 0.5 |
| 7.5 | 73.6 | 0.5 |
| 7.6 | 74.6 | 1 |
| 7.7 | 75.6 | 2.1 |
| 7.8 | 76.5 | 6.9 |
| 7.9 | 77.5 | 13.2 |
| 8 | 78.5 | 17.7 |
| 8.1 | 79.5 | 20.9 |
| 8.2 | 80.4 | 21.5 |
| 8.3 | 81.4 | 27 |
| 8.4 | 82.4 | 27.4 |
| 8.5 | 83.4 | 24.5 |
| 8.6 | 84.3 | 23.2 |
| 8.7 | 85.3 | 26.2 |
| 8.8 | 86.3 | 24.3 |
| 8.9 | 87.3 | 26.2 |
| 9 | 88.2 | 23.2 |
| 9.1 | 89.2 | 22.7 |
| 9.2 | 90.2 | 22.9 |
| 9.3 | 91.1 | 24 |
| 9.4 | 92.1 | 20.9 |
| 9.5 | 93.1 | 17.8 |

| | | |
|---|---|---|
| 9.6 | 94.1 | 18.6 |
| 9.7 | 95 | 17.2 |
| 9.8 | 96 | 13.7 |
| 9.9 | 97 | 15 |
| 10 | 97.9 | 11.3 |
| 10.1 | 98.9 | 10.8 |
| 10.2 | 99.9 | 11.6 |
| 10.3 | 100.8 | 9.2 |
| 10.4 | 101.8 | 9.6 |
| 10.5 | 102.8 | 8.7 |
| 10.6 | 103.7 | 8.1 |
| 10.7 | 104.7 | 6.5 |
| 10.8 | 105.7 | 6.4 |
| 10.9 | 106.6 | 6.5 |
| 11 | 107.6 | 7.3 |
| 11.1 | 108.6 | 4.5 |
| 11.2 | 109.5 | 4.3 |
| 11.3 | 110.5 | 2.8 |
| 11.4 | 111.5 | 4.1 |
| 11.5 | 112.4 | 3.2 |
| 11.6 | 113.4 | 3.7 |
| 11.7 | 114.4 | 2.5 |
| 11.8 | 115.3 | 2.6 |
| 11.9 | 116.3 | 1.9 |
| 12 | 117.3 | 1.4 |
| 12.1 | 118.2 | 1.3 |
| 12.2 | 119.2 | 2.3 |
| 12.3 | 120.1 | 1.4 |
| 12.4 | 121.1 | 0.9 |
| 12.5 | 122.1 | 2.1 |




No label
No captions in graph.

V=20 kV

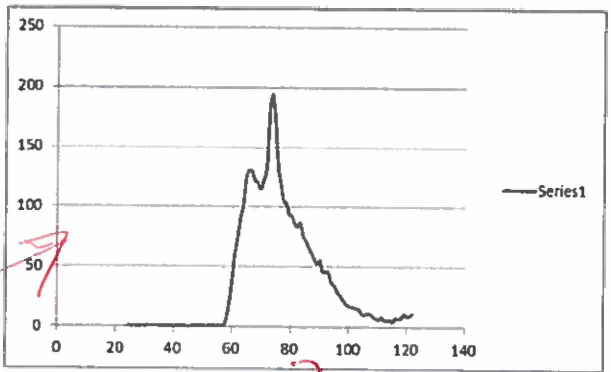
| &b / ° | n&l / pm | R_0 / 1/s |
|---|---|---|
| 2.5 | 24.6 | 1.3 |
| 2.6 | 25.6 | 0.7 |
| 2.7 | 26.6 | 0.8 |
| 2.8 | 27.6 | 0.8 |
| 2.9 | 28.5 | 0.4 |
| 3 | 29.5 | 1.2 |
| 3.1 | 30.5 | 0.6 |
| 3.2 | 31.5 | 1.6 |
| 3.3 | 32.5 | 0.9 |
| 3.4 | 33.4 | 1.2 |
| 3.5 | 34.4 | 1.2 |
| 3.6 | 35.4 | 0.8 |
| 3.7 | 36.4 | 0.6 |
| 3.8 | 37.4 | 0.6 |
| 3.9 | 38.4 | 1.2 |
| 4 | 39.3 | 0.8 |
| 4.1 | 40.3 | 0.5 |
| 4.2 | 41.3 | 1 |
| 4.3 | 42.3 | 0.9 |
| 4.4 | 43.3 | 0.9 |
| 4.5 | 44.3 | 0.8 |
| 4.6 | 45.2 | 0.5 |
| 4.7 | 46.2 | 0.7 |
| 4.8 | 47.2 | 1.3 |
| 4.9 | 48.2 | 1.5 |
| 5 | 49.2 | 1.3 |
| 5.1 | 50.1 | 1.5 |
| 5.2 | 51.1 | 0.6 |
| 5.3 | 52.1 | 1.1 |
| 5.4 | 53.1 | 1.2 |
| 5.5 | 54.1 | 1.4 |
| 5.6 | 55 | 0.9 |
| 5.7 | 56 | 1 |
| 5.8 | 57 | 1.6 |
| 5.9 | 58 | 4.9 |
| 6 | 59 | 18.9 |
| 6.1 | 59.9 | 35 |
| 6.2 | 60.9 | 58.8 |

| | | |
|---|---|---|
| 6.3 | 61.9 | 72.7 |
| 6.4 | 62.9 | 90.7 |
| 6.5 | 63.8 | 101.1 |
| 6.6 | 64.8 | 124.6 |
| 6.7 | 65.8 | 130.5 |
| 6.8 | 66.8 | 129.2 |
| 6.9 | 67.8 | 122 |
| 7 | 68.7 | 120.3 |
| 7.1 | 69.7 | 114.8 |
| 7.2 | 70.7 | 122.2 |
| 7.3 | 71.7 | 133.4 |
| 7.4 | 72.6 | 180.9 |
| 7.5 | 73.6 | 194 |
| 7.6 | 74.6 | 169.8 |
| 7.7 | 75.6 | 132.7 |
| 7.8 | 76.5 | 119.9 |
| 7.9 | 77.5 | 105.8 |
| 8 | 78.5 | 103.3 |
| 8.1 | 79.5 | 93.7 |
| 8.2 | 80.4 | 93 |
| 8.3 | 81.4 | 86.4 |
| 8.4 | 82.4 | 83.7 |
| 8.5 | 83.4 | 86.8 |
| 8.6 | 84.3 | 76.3 |
| 8.7 | 85.3 | 72.3 |
| 8.8 | 86.3 | 66.5 |
| 8.9 | 87.3 | 61.6 |
| 9 | 88.2 | 57 |
| 9.1 | 89.2 | 52.7 |
| 9.2 | 90.2 | 55.3 |
| 9.3 | 91.1 | 46.1 |
| 9.4 | 92.1 | 46.7 |
| 9.5 | 93.1 | 45 |
| 9.6 | 94.1 | 37 |
| 9.7 | 95 | 35 |
| 9.8 | 96 | 29.7 |
| 9.9 | 97 | 26.9 |
| 10 | 97.9 | 23.7 |
| 10.1 | 98.9 | 20.2 |
| 10.2 | 99.9 | 18.1 |
| 10.3 | 100.8 | 17.1 |

| | | |
|---|---|---|
| 10.4 | 101.8 | 16.7 |
| 10.5 | 102.8 | 15.9 |
| 10.6 | 103.7 | 14.8 |
| 10.7 | 104.7 | 11.2 |
| 10.8 | 105.7 | 10.5 |
| 10.9 | 106.6 | 11.8 |
| 11 | 107.6 | 11 |
| 11.1 | 108.6 | 8.9 |
| 11.2 | 109.5 | 7.6 |
| 11.3 | 110.5 | 6.8 |
| 11.4 | 111.5 | 8.7 |
| 11.5 | 112.4 | 6 |
| 11.6 | 113.4 | 6.1 |
| 11.7 | 114.4 | 6.3 |
| 11.8 | 115.3 | 4.4 |
| 11.9 | 116.3 | 7.8 |
| 12 | 117.3 | 7.2 |
| 12.1 | 118.2 | 7.9 |
| 12.2 | 119.2 | 11.1 |
| 12.3 | 120.1 | 8.9 |
| 12.4 | 121.1 | 9.5 |
| 12.5 | 122.1 | 11.3 |

You could have arranged all these table in one page!

This is not how you write report




?

label graph

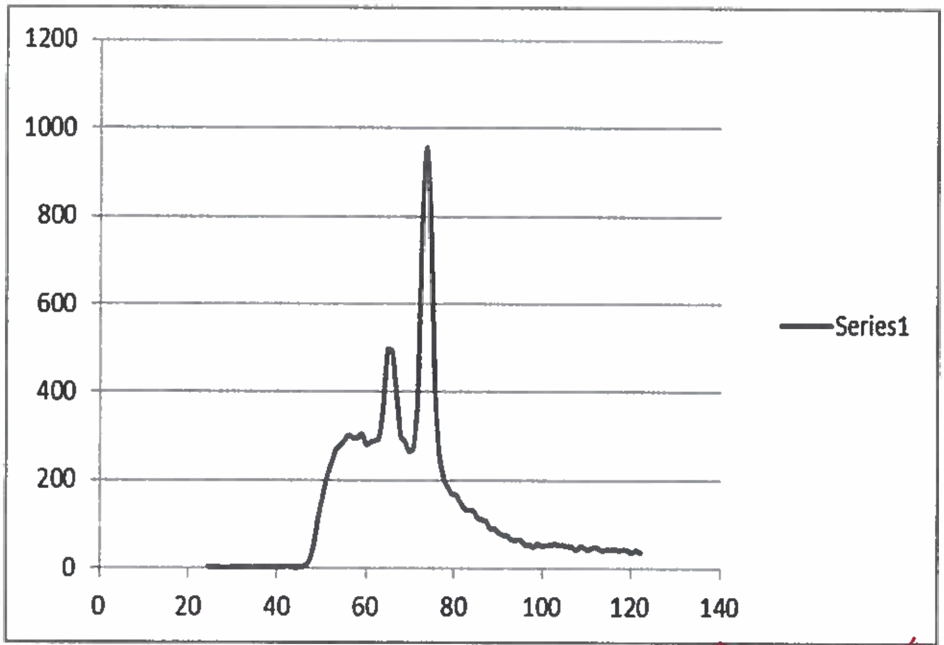
V=25 kV

| &b / ° | n&l / pm | R_0 / 1/s |
|---|---|---|
| 2.5 | 24.6 | 4 |
| 2.6 | 25.6 | 2.6 |
| 2.7 | 26.6 | 3 |
| 2.8 | 27.6 | 2.5 |
| 2.9 | 28.5 | 2.4 |
| 3 | 29.5 | 2.4 |
| 3.1 | 30.5 | 3.9 |
| 3.2 | 31.5 | 2.6 |

| | | |
|---|---|---|
| 3.3 | 32.5 | 3.6 |
| 3.4 | 33.4 | 4 |
| 3.5 | 34.4 | 2.5 |
| 3.6 | 35.4 | 3.3 |
| 3.7 | 36.4 | 3.4 |
| 3.8 | 37.4 | 3.3 |
| 3.9 | 38.4 | 3.4 |
| 4 | 39.3 | 4.4 |
| 4.1 | 40.3 | 3.6 |
| 4.2 | 41.3 | 3.6 |
| 4.3 | 42.3 | 4.6 |
| 4.4 | 43.3 | 4.1 |
| 4.5 | 44.3 | 2.9 |
| 4.6 | 45.2 | 4.1 |
| 4.7 | 46.2 | 6.4 |
| 4.8 | 47.2 | 19.6 |
| 4.9 | 48.2 | 58.4 |
| 5 | 49.2 | 118.7 |
| 5.1 | 50.1 | 161.9 |
| 5.2 | 51.1 | 206.9 |
| 5.3 | 52.1 | 238.4 |
| 5.4 | 53.1 | 268.2 |
| 5.5 | 54.1 | 280.1 |
| 5.6 | 55 | 290.1 |
| 5.7 | 56 | 302.3 |
| 5.8 | 57 | 295.8 |
| 5.9 | 58 | 296.9 |
| 6 | 59 | 304.2 |
| 6.1 | 59.9 | 282 |
| 6.2 | 60.9 | 286.2 |
| 6.3 | 61.9 | 290.9 |
| 6.4 | 62.9 | 296.6 |
| 6.5 | 63.8 | 366 |
| 6.6 | 64.8 | 496.5 |
| 6.7 | 65.8 | 492.4 |
| 6.8 | 66.8 | 399.8 |
| 6.9 | 67.8 | 300.9 |
| 7 | 68.7 | 289.2 |
| 7.1 | 69.7 | 267.2 |
| 7.2 | 70.7 | 274.4 |
| 7.3 | 71.7 | 399.5 |

| | | |
|---|---|---|
| 7.4 | 72.6 | 770.4 |
| 7.5 | 73.6 | 956 |
| 7.6 | 74.6 | 782.3 |
| 7.7 | 75.6 | 414.8 |
| 7.8 | 76.5 | 275.1 |
| 7.9 | 77.5 | 209.6 |
| 8 | 78.5 | 186.2 |
| 8.1 | 79.5 | 170.4 |
| 8.2 | 80.4 | 166.8 |
| 8.3 | 81.4 | 149.7 |
| 8.4 | 82.4 | 135 |
| 8.5 | 83.4 | 133.7 |
| 8.6 | 84.3 | 131.4 |
| 8.7 | 85.3 | 116.3 |
| 8.8 | 86.3 | 111.5 |
| 8.9 | 87.3 | 107.9 |
| 9 | 88.2 | 91.8 |
| 9.1 | 89.2 | 91.8 |
| 9.2 | 90.2 | 82.4 |
| 9.3 | 91.1 | 77.3 |
| 9.4 | 92.1 | 74.9 |
| 9.5 | 93.1 | 65.7 |
| 9.6 | 94.1 | 65.7 |
| 9.7 | 95 | 65.6 |
| 9.8 | 96 | 55.7 |
| 9.9 | 97 | 55.3 |
| 10 | 97.9 | 50.2 |
| 10.1 | 98.9 | 57.4 |
| 10.2 | 99.9 | 51.8 |
| 10.3 | 100.8 | 53.7 |
| 10.4 | 101.8 | 54.3 |
| 10.5 | 102.8 | 56.5 |
| 10.6 | 103.7 | 54 |
| 10.7 | 104.7 | 53.7 |
| 10.8 | 105.7 | 52.1 |
| 10.9 | 106.6 | 50.6 |
| 11 | 107.6 | 43 |
| 11.1 | 108.6 | 51.6 |
| 11.2 | 109.5 | 46.8 |
| 11.3 | 110.5 | 44 |
| 11.4 | 111.5 | 49.4 |

| | | |
|---|---|---|
| 11.5 | 112.4 | 48.5 |
| 11.6 | 113.4 | 42.1 |
| 11.7 | 114.4 | 43.5 |
| 11.8 | 115.3 | 43.6 |
| 11.9 | 116.3 | 45.9 |
| 12 | 117.3 | 42.4 |
| 12.1 | 118.2 | 44.4 |
| 12.2 | 119.2 | 42.3 |
| 12.3 | 120.1 | 37.6 |
| 12.4 | 121.1 | 42.6 |
| 12.5 | 122.1 | 37.4 |




table, figure, caption.

V=30 kV

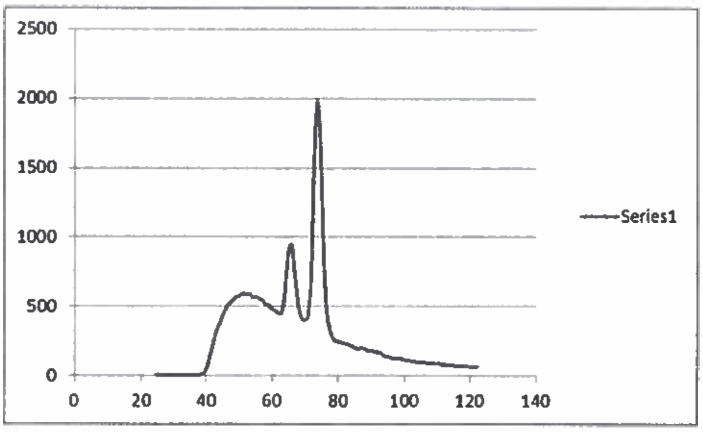
| &b / ° | n&l / pm | R_0 / 1/s |
|---|---|---|
| 2.5 | 24.6 | 9.6 |
| 2.6 | 25.6 | 7.9 |
| 2.7 | 26.6 | 6.1 |
| 2.8 | 27.6 | 7.5 |
| 2.9 | 28.5 | 6.6 |

table — captions

| | | |
|---|---|---|
| 3 | 29.5 | 5.4 |
| 3.1 | 30.5 | 6.5 |
| 3.2 | 31.5 | 6.5 |
| 3.3 | 32.5 | 8.5 |
| 3.4 | 33.4 | 6.9 |
| 3.5 | 34.4 | 8.8 |
| 3.6 | 35.4 | 8.3 |
| 3.7 | 36.4 | 8 |
| 3.8 | 37.4 | 7.8 |
| 3.9 | 38.4 | 10.7 |
| 4 | 39.3 | 20 |
| 4.1 | 40.3 | 69 |
| 4.2 | 41.3 | 169.7 |
| 4.3 | 42.3 | 265.8 |
| 4.4 | 43.3 | 343.5 |
| 4.5 | 44.3 | 398.9 |
| 4.6 | 45.2 | 457.6 |
| 4.7 | 46.2 | 503.3 |
| 4.8 | 47.2 | 526.5 |
| 4.9 | 48.2 | 555.3 |
| 5 | 49.2 | 571.9 |
| 5.1 | 50.1 | 581 |
| 5.2 | 51.1 | 595 |
| 5.3 | 52.1 | 589.2 |
| 5.4 | 53.1 | 593.2 |
| 5.5 | 54.1 | 565 |
| 5.6 | 55 | 572.8 |
| 5.7 | 56 | 555.2 |
| 5.8 | 57 | 545.2 |
| 5.9 | 58 | 516.2 |
| 6 | 59 | 508.8 |
| 6.1 | 59.9 | 483.3 |
| 6.2 | 60.9 | 471.3 |
| 6.3 | 61.9 | 451.4 |
| 6.4 | 62.9 | 461.3 |
| 6.5 | 63.8 | 601.4 |
| 6.6 | 64.8 | 876.1 |
| 6.7 | 65.8 | 944.5 |
| 6.8 | 66.8 | 722.6 |
| 6.9 | 67.8 | 512.7 |
| 7 | 68.7 | 423.9 |

| | | |
|---|---|---|
| 7.1 | 69.7 | 404.3 |
| 7.2 | 70.7 | 425.3 |
| 7.3 | 71.7 | 677 |
| 7.4 | 72.6 | 1481.8 |
| 7.5 | 73.6 | 1971.8 |
| 7.6 | 74.6 | 1626.1 |
| 7.7 | 75.6 | 852.4 |
| 7.8 | 76.5 | 466.5 |
| 7.9 | 77.5 | 326.5 |
| 8 | 78.5 | 265.2 |
| 8.1 | 79.5 | 251.2 |
| 8.2 | 80.4 | 247.8 |
| 8.3 | 81.4 | 237.2 |
| 8.4 | 82.4 | 231.3 |
| 8.5 | 83.4 | 222.4 |
| 8.6 | 84.3 | 212.9 |
| 8.7 | 85.3 | 199.1 |
| 8.8 | 86.3 | 198.4 |
| 8.9 | 87.3 | 203.4 |
| 9 | 88.2 | 191.9 |
| 9.1 | 89.2 | 179.7 |
| 9.2 | 90.2 | 181.8 |
| 9.3 | 91.1 | 173.4 |
| 9.4 | 92.1 | 173.9 |
| 9.5 | 93.1 | 162.9 |
| 9.6 | 94.1 | 142.2 |
| 9.7 | 95 | 143.5 |
| 9.8 | 96 | 129.2 |
| 9.9 | 97 | 129.2 |
| 10 | 97.9 | 128 |
| 10.1 | 98.9 | 125.2 |
| 10.2 | 99.9 | 115.8 |
| 10.3 | 100.8 | 115.4 |
| 10.4 | 101.8 | 108.5 |
| 10.5 | 102.8 | 108.3 |
| 10.6 | 103.7 | 99.6 |
| 10.7 | 104.7 | 103.6 |
| 10.8 | 105.7 | 101.1 |
| 10.9 | 106.6 | 95 |
| 11 | 107.6 | 91.6 |
| 11.1 | 108.6 | 95.4 |

| | | |
|---|---|---|
| 11.2 | 109.5 | 88.6 |
| 11.3 | 110.5 | 91.8 |
| 11.4 | 111.5 | 82.4 |
| 11.5 | 112.4 | 85.2 |
| 11.6 | 113.4 | 77.2 |
| 11.7 | 114.4 | 79.7 |
| 11.8 | 115.3 | 77.1 |
| 11.9 | 116.3 | 72.4 |
| 12 | 117.3 | 73.1 |
| 12.1 | 118.2 | 71.3 |
| 12.2 | 119.2 | 69.8 |
| 12.3 | 120.1 | 67.1 |
| 12.4 | 121.1 | 68.5 |
| 12.5 | 122.1 | 69.1 |




label graph with units
caption table
& graph

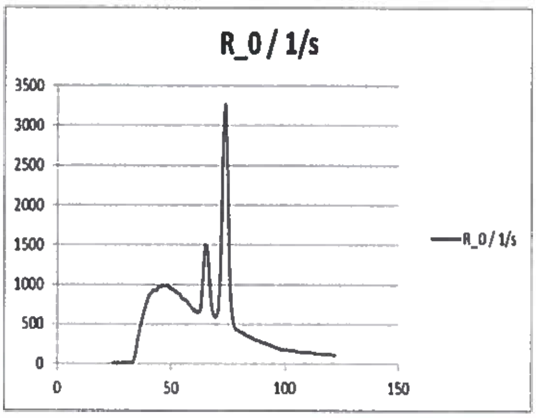
V=35 kV

| &b / ° | n&l / pm | R_0 / 1/s |
|---|---|---|
| 2.5 | 24.6 | 13.4 |
| 2.6 | 25.6 | 15.6 |
| 2.7 | 26.6 | 11.9 |
| 2.8 | 27.6 | 13.8 |
| 2.9 | 28.5 | 14 |
| 3 | 29.5 | 14.7 |
| 3.1 | 30.5 | 12.3 |
| 3.2 | 31.5 | 18.1 |
| 3.3 | 32.5 | 16.7 |
| 3.4 | 33.4 | 30.2 |

| | | |
|---|---|---|
| 3.5 | 34.4 | 109.1 |
| 3.6 | 35.4 | 287.3 |
| 3.7 | 36.4 | 444.4 |
| 3.8 | 37.4 | 574.6 |
| 3.9 | 38.4 | 686 |
| 4 | 39.3 | 769.3 |
| 4.1 | 40.3 | 858.9 |
| 4.2 | 41.3 | 897.2 |
| 4.3 | 42.3 | 938.6 |
| 4.4 | 43.3 | 922.6 |
| 4.5 | 44.3 | 967.2 |
| 4.6 | 45.2 | 982 |
| 4.7 | 46.2 | 988.2 |
| 4.8 | 47.2 | 988.8 |
| 4.9 | 48.2 | 988.4 |
| 5 | 49.2 | 959.4 |
| 5.1 | 50.1 | 956.1 |
| 5.2 | 51.1 | 937.4 |
| 5.3 | 52.1 | 919 |
| 5.4 | 53.1 | 894.2 |
| 5.5 | 54.1 | 874.7 |
| 5.6 | 55 | 828.5 |
| 5.7 | 56 | 823 |
| 5.8 | 57 | 797.3 |
| 5.9 | 58 | 754.6 |
| 6 | 59 | 713.4 |
| 6.1 | 59.9 | 694.2 |
| 6.2 | 60.9 | 671.6 |
| 6.3 | 61.9 | 651 |
| 6.4 | 62.9 | 709.9 |
| 6.5 | 63.8 | 1041.8 |
| 6.6 | 64.8 | 1502.5 |
| 6.7 | 65.8 | 1453.4 |
| 6.8 | 66.8 | 1022.2 |
| 6.9 | 67.8 | 706.7 |
| 7 | 68.7 | 615.3 |
| 7.1 | 69.7 | 605.8 |
| 7.2 | 70.7 | 712.6 |
| 7.3 | 71.7 | 1385 |
| 7.4 | 72.6 | 2746.9 |
| 7.5 | 73.6 | 3263.2 |

| | | |
|---|---|---|
| 7.6 | 74.6 | 2424.4 |
| 7.7 | 75.6 | 1158.4 |
| 7.8 | 76.5 | 688.8 |
| 7.9 | 77.5 | 494.4 |
| 8 | 78.5 | 438.5 |
| 8.1 | 79.5 | 426.3 |
| 8.2 | 80.4 | 405.1 |
| 8.3 | 81.4 | 395 |
| 8.4 | 82.4 | 374.7 |
| 8.5 | 83.4 | 355.1 |
| 8.6 | 84.3 | 345.8 |
| 8.7 | 85.3 | 339.4 |
| 8.8 | 86.3 | 316.9 |
| 8.9 | 87.3 | 307.1 |
| 9 | 88.2 | 297.9 |
| 9.1 | 89.2 | 287 |
| 9.2 | 90.2 | 273.2 |
| 9.3 | 91.1 | 266.2 |
| 9.4 | 92.1 | 259.5 |
| 9.5 | 93.1 | 245.8 |
| 9.6 | 94.1 | 233.6 |
| 9.7 | 95 | 222.4 |
| 9.8 | 96 | 211.1 |
| 9.9 | 97 | 203.7 |
| 10 | 97.9 | 193.6 |
| 10.1 | 98.9 | 182.5 |
| 10.2 | 99.9 | 177.8 |
| 10.3 | 100.8 | 183 |
| 10.4 | 101.8 | 174 |
| 10.5 | 102.8 | 177.6 |
| 10.6 | 103.7 | 169.7 |
| 10.7 | 104.7 | 166.7 |
| 10.8 | 105.7 | 154.7 |
| 10.9 | 106.6 | 151.6 |
| 11 | 107.6 | 153.1 |
| 11.1 | 108.6 | 148 |
| 11.2 | 109.5 | 147.7 |
| 11.3 | 110.5 | 150.5 |
| 11.4 | 111.5 | 146.4 |
| 11.5 | 112.4 | 139 |
| 11.6 | 113.4 | 136.4 |

| | | |
|---|---|---|
| 11.7 | 114.4 | 132.1 |
| 11.8 | 115.3 | 130.8 |
| 11.9 | 116.3 | 134.8 |
| 12 | 117.3 | 121.7 |
| 12.1 | 118.2 | 122.5 |
| 12.2 | 119.2 | 127.9 |
| 12.3 | 120.1 | 123.6 |
| 12.4 | 121.1 | 119 |
| 12.5 | 122.1 | 113.1 |




Put all graphs in one bigger graph.

you need to show this in graph

Here the x-axis represents the angle or the transformed wavelength and the y-axis represents the count rate.

| V(kV) | λ(Kα) | λ(Kβ) |
|---|---|---|
| 25 | 73.6 | 65.8 |
| 30 | 73.6 | 64.8 |
| 35 | 73.6 | 64.8 |

Mean of λ(Kα)=73.6 & λ(Kβ)=65.13.The expected results for λ(Kα)=71.08 & λ(Kβ)=63.095.

In this part we set the current to be 1 mA and set the upper and lower limits to be 2.5 and 12.5 degree respectively .The $\Delta t = 10s$ &$\Delta\beta = 0.1°$ for this experiment.The values where taken for both the angles and then changed to the corresponding wavelength of NaCl crystal .From these results we can notice that for 15 & 20 kV the characteristic peaks where not existent.This arises from that the potential energy required for production of characteristic X-rays have not been met yet.However, we can notice that the K-characteristic peaks are deformed slightly but is trending towards it. But for higher voltage the characteristics appear clearly as the electrons exceeds the threshold for the production of the x-ray.The spectrum get continuously deformed to sharper and higher intensity characteristic peaks which is called hardening.We notice that the position more or less stay the same.

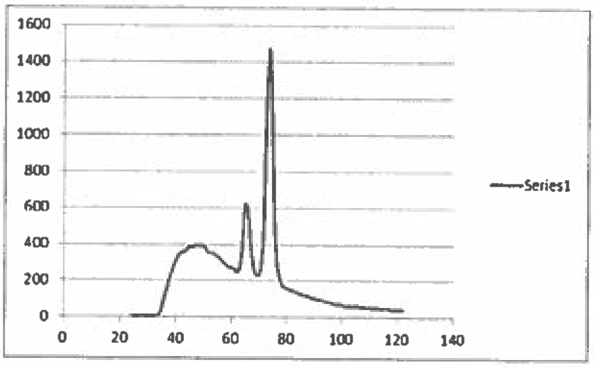
b)Now we changed the current while keeping the voltage constant (V=35 kV) repeat the same experiment for the last one.The other conditions where similar to the last experiment.These are the results we got:

I=0.4 mA

| &b / | n&l / pm | R_0 / 1/s |
|---|---|---|
| 2.5 | 24.6 | 5.5 |
| 2.6 | 25.6 | 4.9 |
| 2.7 | 26.6 | 5.9 |
| 2.8 | 27.6 | 5.8 |
| 2.9 | 28.5 | 6.1 |
| 3 | 29.5 | 6.4 |
| 3.1 | 30.5 | 6.2 |
| 3.2 | 31.5 | 4.7 |
| 3.3 | 32.5 | 5.7 |
| 3.4 | 33.4 | 8 |
| 3.5 | 34.4 | 25.9 |
| 3.6 | 35.4 | 83.6 |
| 3.7 | 36.4 | 143.1 |
| 3.8 | 37.4 | 202.3 |
| 3.9 | 38.4 | 246 |
| 4 | 39.3 | 284.8 |
| 4.1 | 40.3 | 324.3 |
| 4.2 | 41.3 | 348.8 |
| 4.3 | 42.3 | 359.7 |
| 4.4 | 43.3 | 362.7 |
| 4.5 | 44.3 | 378.4 |
| 4.6 | 45.2 | 388.3 |
| 4.7 | 46.2 | 384.9 |
| 4.8 | 47.2 | 397.5 |
| 4.9 | 48.2 | 393.6 |
| 5 | 49.2 | 391.7 |
| 5.1 | 50.1 | 387.2 |
| 5.2 | 51.1 | 368.7 |
| 5.3 | 52.1 | 352.3 |
| 5.4 | 53.1 | 356.1 |
| 5.5 | 54.1 | 342.2 |
| 5.6 | 55 | 334 |
| 5.7 | 56 | 319.8 |
| 5.8 | 57 | 304 |

| | | |
|---|---|---|
| 5.9 | 58 | 288 |
| 6 | 59 | 276.4 |
| 6.1 | 59.9 | 273.4 |
| 6.2 | 60.9 | 265 |
| 6.3 | 61.9 | 251.3 |
| 6.4 | 62.9 | 268.1 |
| 6.5 | 63.8 | 372.9 |
| 6.6 | 64.8 | 620.6 |
| 6.7 | 65.8 | 597.5 |
| 6.8 | 66.8 | 421.5 |
| 6.9 | 67.8 | 289 |
| 7 | 68.7 | 239.7 |
| 7.1 | 69.7 | 231.9 |
| 7.2 | 70.7 | 265.1 |
| 7.3 | 71.7 | 489.3 |
| 7.4 | 72.6 | 1138.4 |
| 7.5 | 73.6 | 1474.5 |
| 7.6 | 74.6 | 1124 |
| 7.7 | 75.6 | 558.6 |
| 7.8 | 76.5 | 304.9 |
| 7.9 | 77.5 | 218.1 |
| 8 | 78.5 | 174.9 |
| 8.1 | 79.5 | 166 |
| 8.2 | 80.4 | 159.4 |
| 8.3 | 81.4 | 150.8 |
| 8.4 | 82.4 | 146.1 |
| 8.5 | 83.4 | 138.5 |
| 8.6 | 84.3 | 134.7 |
| 8.7 | 85.3 | 127.3 |
| 8.8 | 86.3 | 122.1 |
| 8.9 | 87.3 | 119.7 |
| 9 | 88.2 | 116.1 |
| 9.1 | 89.2 | 109.3 |
| 9.2 | 90.2 | 104.7 |
| 9.3 | 91.1 | 99.5 |
| 9.4 | 92.1 | 99.2 |
| 9.5 | 93.1 | 96.3 |
| 9.6 | 94.1 | 89.5 |
| 9.7 | 95 | 86.1 |
| 9.8 | 96 | 84.4 |
| 9.9 | 97 | 78.4 |

| | | |
|---|---|---|
| 10 | 97.9 | 73.3 |
| 10.1 | 98.9 | 70.9 |
| 10.2 | 99.9 | 75.1 |
| 10.3 | 100.8 | 65.8 |
| 10.4 | 101.8 | 62.7 |
| 10.5 | 102.8 | 65.5 |
| 10.6 | 103.7 | 59.9 |
| 10.7 | 104.7 | 62.8 |
| 10.8 | 105.7 | 63.4 |
| 10.9 | 106.6 | 59.7 |
| 11 | 107.6 | 60 |
| 11.1 | 108.6 | 56.7 |
| 11.2 | 109.5 | 59 |
| 11.3 | 110.5 | 56.2 |
| 11.4 | 111.5 | 53.6 |
| 11.5 | 112.4 | 54.2 |
| 11.6 | 113.4 | 51.6 |
| 11.7 | 114.4 | 49.4 |
| 11.8 | 115.3 | 52.2 |
| 11.9 | 116.3 | 50.6 |
| 12 | 117.3 | 49.9 |
| 12.1 | 118.2 | 44.5 |
| 12.2 | 119.2 | 46.3 |
| 12.3 | 120.1 | 46.6 |
| 12.4 | 121.1 | 47.7 |
| 12.5 | 122.1 | 43.4 |




Label & caption graph

I=0.6 mA

| &b / ° | n&l / pm | R_0 / 1/s |
|---|---|---|
| 2.5 | 24.6 | 6.6 |

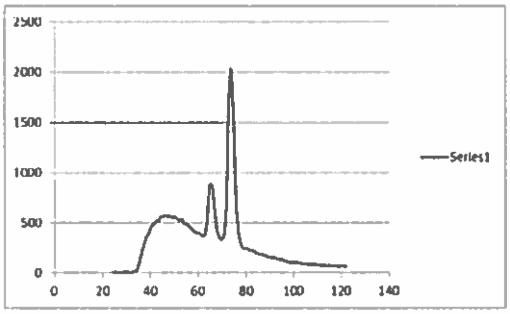
| | | |
|---|---|---|
| 2.6 | 25.6 | 8.9 |
| 2.7 | 26.6 | 6 |
| 2.8 | 27.6 | 7.2 |
| 2.9 | 28.5 | 8.1 |
| 3 | 29.5 | 7.9 |
| 3.1 | 30.5 | 8.1 |
| 3.2 | 31.5 | 8.9 |
| 3.3 | 32.5 | 8.4 |
| 3.4 | 33.4 | 11.6 |
| 3.5 | 34.4 | 33.3 |
| 3.6 | 35.4 | 109.2 |
| 3.7 | 36.4 | 207.9 |
| 3.8 | 37.4 | 288.7 |
| 3.9 | 38.4 | 363.7 |
| 4 | 39.3 | 398.7 |
| 4.1 | 40.3 | 461.9 |
| 4.2 | 41.3 | 483.1 |
| 4.3 | 42.3 | 522.3 |
| 4.4 | 43.3 | 517.3 |
| 4.5 | 44.3 | 554 |
| 4.6 | 45.2 | 562.2 |
| 4.7 | 46.2 | 571.2 |
| 4.8 | 47.2 | 565.6 |
| 4.9 | 48.2 | 564.2 |
| 5 | 49.2 | 555.2 |
| 5.1 | 50.1 | 560.7 |
| 5.2 | 51.1 | 542.8 |
| 5.3 | 52.1 | 529.1 |
| 5.4 | 53.1 | 537.3 |
| 5.5 | 54.1 | 496.9 |
| 5.6 | 55 | 484 |
| 5.7 | 56 | 468.8 |
| 5.8 | 57 | 442.8 |
| 5.9 | 58 | 423 |
| 6 | 59 | 405 |
| 6.1 | 59.9 | 401.2 |
| 6.2 | 60.9 | 390 |
| 6.3 | 61.9 | 364 |
| 6.4 | 62.9 | 389.9 |
| 6.5 | 63.8 | 547.8 |
| 6.6 | 64.8 | 882 |

Put all data in one page! It's very ugly.

| | | |
|---|---|---|
| 6.7 | 65.8 | 865.6 |
| 6.8 | 66.8 | 631.4 |
| 6.9 | 67.8 | 425.8 |
| 7 | 68.7 | 362.1 |
| 7.1 | 69.7 | 333.1 |
| 7.2 | 70.7 | 385.5 |
| 7.3 | 71.7 | 690.9 |
| 7.4 | 72.6 | 1561.6 |
| 7.5 | 73.6 | 2032 |
| 7.6 | 74.6 | 1614.3 |
| 7.7 | 75.6 | 803.8 |
| 7.8 | 76.5 | 460.6 |
| 7.9 | 77.5 | 318.5 |
| 8 | 78.5 | 251.9 |
| 8.1 | 79.5 | 246.1 |
| 8.2 | 80.4 | 242.3 |
| 8.3 | 81.4 | 226.1 |
| 8.4 | 82.4 | 224.4 |
| 8.5 | 83.4 | 213.5 |
| 8.6 | 84.3 | 200 |
| 8.7 | 85.3 | 185.6 |
| 8.8 | 86.3 | 185.3 |
| 8.9 | 87.3 | 181 |
| 9 | 88.2 | 168.5 |
| 9.1 | 89.2 | 160.6 |
| 9.2 | 90.2 | 155.5 |
| 9.3 | 91.1 | 150.8 |
| 9.4 | 92.1 | 153.9 |
| 9.5 | 93.1 | 135.4 |
| 9.6 | 94.1 | 134.8 |
| 9.7 | 95 | 135.2 |
| 9.8 | 96 | 119.1 |
| 9.9 | 97 | 116 |
| 10 | 97.9 | 104.5 |
| 10.1 | 98.9 | 105.5 |
| 10.2 | 99.9 | 106.1 |
| 10.3 | 100.8 | 99.6 |
| 10.4 | 101.8 | 102.4 |
| 10.5 | 102.8 | 99.7 |
| 10.6 | 103.7 | 91 |
| 10.7 | 104.7 | 89.6 |

| | | |
|---|---|---|
| 10.8 | 105.7 | 86.3 |
| 10.9 | 106.6 | 89.8 |
| 11 | 107.6 | 87.6 |
| 11.1 | 108.6 | 82.5 |
| 11.2 | 109.5 | 83.3 |
| 11.3 | 110.5 | 78.1 |
| 11.4 | 111.5 | 77 |
| 11.5 | 112.4 | 78.4 |
| 11.6 | 113.4 | 74.2 |
| 11.7 | 114.4 | 75.7 |
| 11.8 | 115.3 | 72.8 |
| 11.9 | 116.3 | 73.1 |
| 12 | 117.3 | 66.8 |
| 12.1 | 118.2 | 70.2 |
| 12.2 | 119.2 | 65.1 |
| 12.3 | 120.1 | 72.7 |
| 12.4 | 121.1 | 64.6 |
| 12.5 | 122.1 | 64.5 |

caption




label & caption

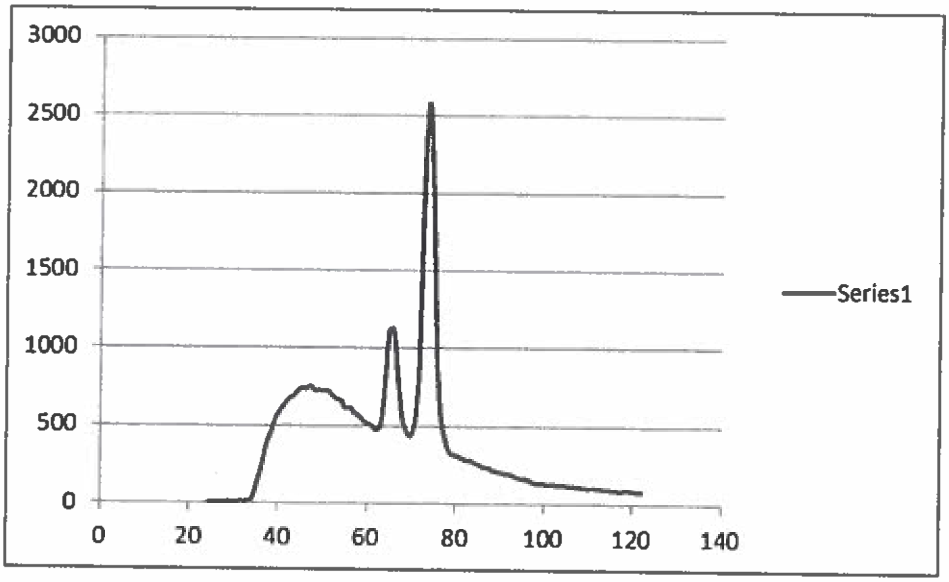
I=0.8 mA

| &b / ° | n&l / pm | R_0 / 1/s |
|---|---|---|
| 2.5 | 24.6 | 10.4 |
| 2.6 | 25.6 | 8.9 |
| 2.7 | 26.6 | 10.8 |
| 2.8 | 27.6 | 9.8 |
| 2.9 | 28.5 | 10.8 |
| 3 | 29.5 | 11 |
| 3.1 | 30.5 | 9.8 |
| 3.2 | 31.5 | 13.3 |
| 3.3 | 32.5 | 12 |
| 3.4 | 33.4 | 15.9 |

| | | |
|---|---|---|
| 3.5 | 34.4 | 41.2 |
| 3.6 | 35.4 | 144.3 |
| 3.7 | 36.4 | 250.4 |
| 3.8 | 37.4 | 378.5 |
| 3.9 | 38.4 | 459.7 |
| 4 | 39.3 | 539.4 |
| 4.1 | 40.3 | 595 |
| 4.2 | 41.3 | 636.5 |
| 4.3 | 42.3 | 672.7 |
| 4.4 | 43.3 | 691.5 |
| 4.5 | 44.3 | 722.7 |
| 4.6 | 45.2 | 747 |
| 4.7 | 46.2 | 742.4 |
| 4.8 | 47.2 | 759 |
| 4.9 | 48.2 | 728.5 |
| 5 | 49.2 | 733.5 |
| 5.1 | 50.1 | 726 |
| 5.2 | 51.1 | 727.2 |
| 5.3 | 52.1 | 698.8 |
| 5.4 | 53.1 | 673.1 |
| 5.5 | 54.1 | 667 |
| 5.6 | 55 | 618.2 |
| 5.7 | 56 | 621.6 |
| 5.8 | 57 | 588.5 |
| 5.9 | 58 | 569 |
| 6 | 59 | 538.6 |
| 6.1 | 59.9 | 520.6 |
| 6.2 | 60.9 | 506.4 |
| 6.3 | 61.9 | 477.9 |
| 6.4 | 62.9 | 501.1 |
| 6.5 | 63.8 | 712.9 |
| 6.6 | 64.8 | 1110.9 |
| 6.7 | 65.8 | 1125.1 |
| 6.8 | 66.8 | 805.9 |
| 6.9 | 67.8 | 550.9 |
| 7 | 68.7 | 473.2 |
| 7.1 | 69.7 | 440.6 |
| 7.2 | 70.7 | 517.8 |
| 7.3 | 71.7 | 890 |
| 7.4 | 72.6 | 1995 |
| 7.5 | 73.6 | 2582.5 |

| | | |
|---|---|---|
| 7.6 | 74.6 | 2093.6 |
| 7.7 | 75.6 | 1047.4 |
| 7.8 | 76.5 | 596.9 |
| 7.9 | 77.5 | 425.4 |
| 8 | 78.5 | 338.9 |
| 8.1 | 79.5 | 319.7 |
| 8.2 | 80.4 | 310.6 |
| 8.3 | 81.4 | 297.3 |
| 8.4 | 82.4 | 283.5 |
| 8.5 | 83.4 | 284.5 |
| 8.6 | 84.3 | 266.6 |
| 8.7 | 85.3 | 255.1 |
| 8.8 | 86.3 | 237.7 |
| 8.9 | 87.3 | 236.7 |
| 9 | 88.2 | 220.7 |
| 9.1 | 89.2 | 213.4 |
| 9.2 | 90.2 | 205.5 |
| 9.3 | 91.1 | 198.4 |
| 9.4 | 92.1 | 196.2 |
| 9.5 | 93.1 | 185.7 |
| 9.6 | 94.1 | 172 |
| 9.7 | 95 | 168 |
| 9.8 | 96 | 163.3 |
| 9.9 | 97 | 150.6 |
| 10 | 97.9 | 140.6 |
| 10.1 | 98.9 | 139.2 |
| 10.2 | 99.9 | 136.1 |
| 10.3 | 100.8 | 128.6 |
| 10.4 | 101.8 | 132 |
| 10.5 | 102.8 | 129 |
| 10.6 | 103.7 | 124.8 |
| 10.7 | 104.7 | 126.2 |
| 10.8 | 105.7 | 118 |
| 10.9 | 106.6 | 120.7 |
| 11 | 107.6 | 113.1 |
| 11.1 | 108.6 | 114 |
| 11.2 | 109.5 | 106.1 |
| 11.3 | 110.5 | 106.8 |
| 11.4 | 111.5 | 107.6 |
| 11.5 | 112.4 | 107.3 |
| 11.6 | 113.4 | 98 |

| | | |
|---|---|---|
| 11.7 | 114.4 | 102.7 |
| 11.8 | 115.3 | 93.3 |
| 11.9 | 116.3 | 93.4 |
| 12 | 117.3 | 87.1 |
| 12.1 | 118.2 | 93.2 |
| 12.2 | 119.2 | 93.2 |
| 12.3 | 120.1 | 88 |
| 12.4 | 121.1 | 85.7 |
| 12.5 | 122.1 | 83.4 |




I=1 mA

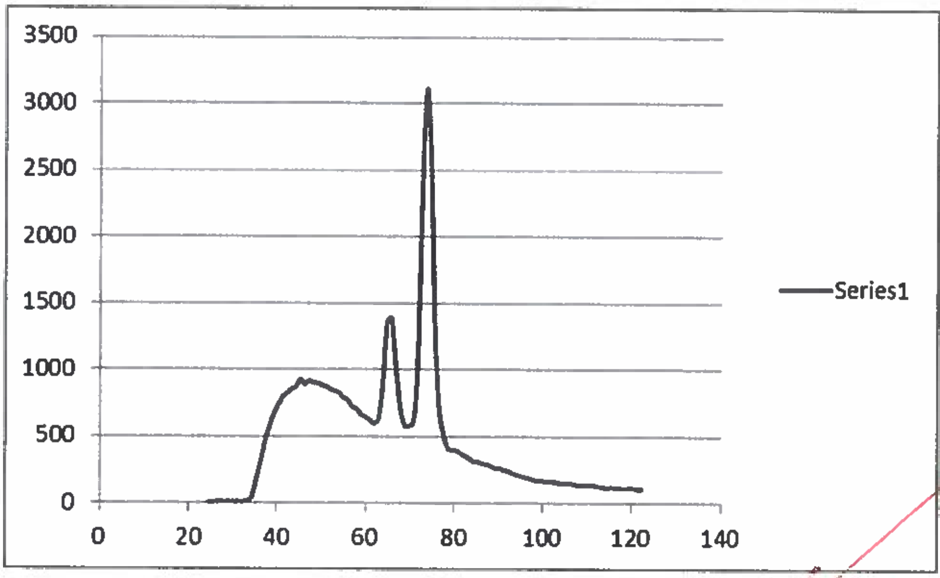
label & caption; Put all ~~graphs~~ curves in one graph.

| &b / ° | n&l / pm | R_0 / 1/s |
|---|---|---|
| 2.5 | 24.6 | 10.9 |
| 2.6 | 25.6 | 12.1 |
| 2.7 | 26.6 | 13.9 |
| 2.8 | 27.6 | 12.9 |
| 2.9 | 28.5 | 13.4 |
| 3 | 29.5 | 14.1 |
| 3.1 | 30.5 | 12.9 |
| 3.2 | 31.5 | 13.8 |
| 3.3 | 32.5 | 15.3 |
| 3.4 | 33.4 | 21.1 |
| 3.5 | 34.4 | 55.1 |

| | | |
|---|---|---|
| 3.6 | 35.4 | 190.7 |
| 3.7 | 36.4 | 329.3 |
| 3.8 | 37.4 | 479 |
| 3.9 | 38.4 | 587.4 |
| 4 | 39.3 | 667 |
| 4.1 | 40.3 | 738.5 |
| 4.2 | 41.3 | 797.6 |
| 4.3 | 42.3 | 824.8 |
| 4.4 | 43.3 | 855.7 |
| 4.5 | 44.3 | 875.7 |
| 4.6 | 45.2 | 924.8 |
| 4.7 | 46.2 | 892 |
| 4.8 | 47.2 | 917.3 |
| 4.9 | 48.2 | 902.4 |
| 5 | 49.2 | 900.1 |
| 5.1 | 50.1 | 883.2 |
| 5.2 | 51.1 | 876.2 |
| 5.3 | 52.1 | 853.7 |
| 5.4 | 53.1 | 842.9 |
| 5.5 | 54.1 | 825.7 |
| 5.6 | 55 | 792.4 |
| 5.7 | 56 | 774.1 |
| 5.8 | 57 | 722.2 |
| 5.9 | 58 | 708 |
| 6 | 59 | 663 |
| 6.1 | 59.9 | 648.6 |
| 6.2 | 60.9 | 623 |
| 6.3 | 61.9 | 600.7 |
| 6.4 | 62.9 | 633.5 |
| 6.5 | 63.8 | 879.3 |
| 6.6 | 64.8 | 1355 |
| 6.7 | 65.8 | 1388.7 |
| 6.8 | 66.8 | 1007.7 |
| 6.9 | 67.8 | 703 |
| 7 | 68.7 | 583.8 |
| 7.1 | 69.7 | 580.4 |
| 7.2 | 70.7 | 610.4 |
| 7.3 | 71.7 | 1065.2 |
| 7.4 | 72.6 | 2334.9 |
| 7.5 | 73.6 | 3109.5 |
| 7.6 | 74.6 | 2564.5 |

| | | |
|---|---|---|
| 7.7 | 75.6 | 1292.9 |
| 7.8 | 76.5 | 736.8 |
| 7.9 | 77.5 | 524.1 |
| 8 | 78.5 | 417.5 |
| 8.1 | 79.5 | 401.8 |
| 8.2 | 80.4 | 397.5 |
| 8.3 | 81.4 | 378 |
| 8.4 | 82.4 | 356.7 |
| 8.5 | 83.4 | 336.9 |
| 8.6 | 84.3 | 316.1 |
| 8.7 | 85.3 | 314.9 |
| 8.8 | 86.3 | 298.6 |
| 8.9 | 87.3 | 295.4 |
| 9 | 88.2 | 281.4 |
| 9.1 | 89.2 | 264.4 |
| 9.2 | 90.2 | 267.6 |
| 9.3 | 91.1 | 251 |
| 9.4 | 92.1 | 245.9 |
| 9.5 | 93.1 | 229.6 |
| 9.6 | 94.1 | 217.4 |
| 9.7 | 95 | 208.6 |
| 9.8 | 96 | 197.7 |
| 9.9 | 97 | 191.4 |
| 10 | 97.9 | 178.9 |
| 10.1 | 98.9 | 173.6 |
| 10.2 | 99.9 | 173.3 |
| 10.3 | 100.8 | 164.4 |
| 10.4 | 101.8 | 166.1 |
| 10.5 | 102.8 | 162.7 |
| 10.6 | 103.7 | 156.2 |
| 10.7 | 104.7 | 154.2 |
| 10.8 | 105.7 | 152.2 |
| 10.9 | 106.6 | 150.9 |
| 11 | 107.6 | 141.7 |
| 11.1 | 108.6 | 138.5 |
| 11.2 | 109.5 | 136.9 |
| 11.3 | 110.5 | 141.1 |
| 11.4 | 111.5 | 137.9 |
| 11.5 | 112.4 | 131.1 |
| 11.6 | 113.4 | 126.3 |
| 11.7 | 114.4 | 120.6 |

| | | |
|---|---|---|
| 11.8 | 115.3 | 124.4 |
| 11.9 | 116.3 | 121.8 |
| 12 | 117.3 | 118.5 |
| 12.1 | 118.2 | 116.1 |
| 12.2 | 119.2 | 117.9 |
| 12.3 | 120.1 | 119.7 |
| 12.4 | 121.1 | 110.3 |
| 12.5 | 122.1 | 110.2 |



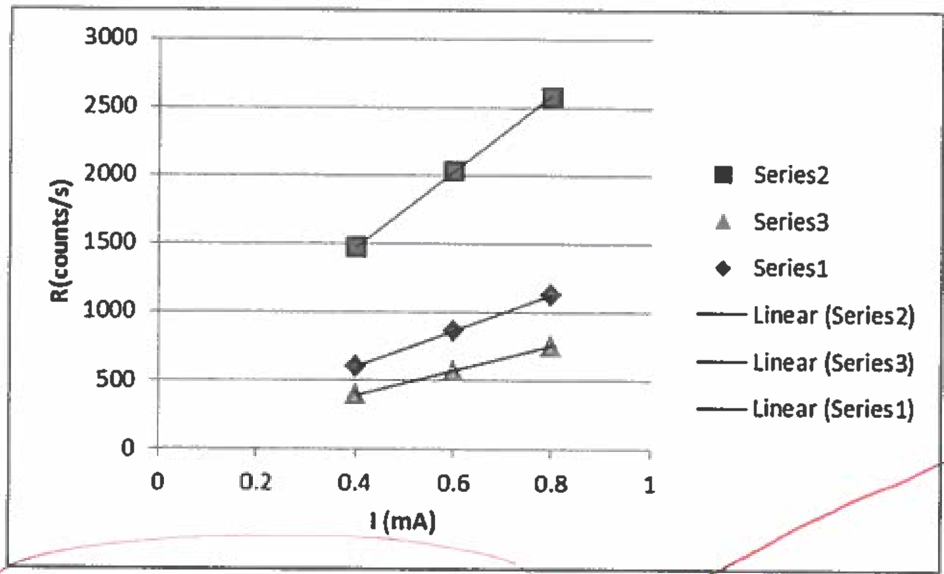

Show the labels in the graph.

Here the x-axis represents the angle or the transformed wavelength and the y-axis represents the count rate.

| I(mA) | λ (Kα) | λ (Kβ) |
|---|---|---|
| 0.4 | 73.6 | 65.8 |
| 0.6 | 73.6 | 65.8 |
| 0.8 | 73.6 | 65.8 |
| 1 | 73.6 | 65.8 |

| I(mA) | R(Kα)($s^{-1}$) | R(Kβ)($s^{-1}$) | R(C) ($s^{-1}$) |
|---|---|---|---|
| 0.4 | 1474.5 | 596.5 | 397.5 |
| 0.6 | 2032 | 865.6 | 571.2 |
| 0.8 | 2582.5 | 1125.1 | 759 |
| 1 | 3109.5 | 1388.7 | 924.8 |

Analogous to the last one we got two characteristic X-rays peaks at the middle of the general x-rays. However the interesting point here is that he position of these did not get shift and their height remains the same which clearly explains that height of the characteristic x-ray peaks is dependent on the potential. Unlike the current which have no effect on the height of the characteristic peaks nor their postions.However, the maximum count rate is altered by the changes in current for the characteristic and even the general x-ray which is exemplified in the values took for the peaks.The count rate resembles the intensity of the x-ray which is related linearly with the current as shown in the figure below:




Red for Kα,Blue Kβ & Green general X-ray

The amazing part here is that the linearity continued even for high values which is not expected. This mean that the dead time effects experienced at high count rates are very small in our case.

**Planck's constant**

In this experiment our main goal is to find the Planck's constant by the utilization of varying voltages. This arises since the minimum wavelength changes inversely with the wavelength.We used the following specifications for the curves used alter to find the planck's constant:

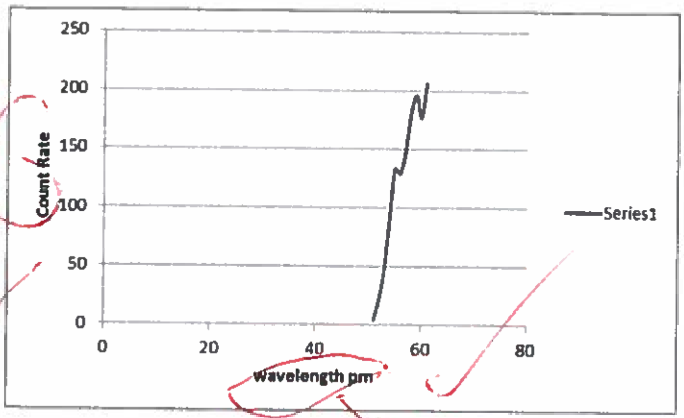
| $\frac{U}{kV}$ | $\frac{I}{mA}$ | $\frac{\Delta t}{s}$ | $\frac{\beta_{min}}{grd}$ | $\frac{\beta_{max}}{grd}$ | $\frac{\Delta\beta}{grd}$ |
|---|---|---|---|---|---|
| 22 | 1.00 | 30 | 5.2 | 6.2 | 0.1 |
| 24 | 1.00 | 30 | 5.0 | 6.2 | 0.1 |
| 26 | 1.00 | 20 | 4.5 | 6.2 | 0.1 |
| 28 | 1.00 | 20 | 3.8 | 6.0 | 0.1 |
| 30 | 1.00 | 10 | 3.2 | 6.0 | 0.1 |
| 32 | 1.00 | 10 | 2.5 | 6.0 | 0.1 |
| 34 | 1.00 | 10 | 2.5 | 6.0 | 0.1 |
| 35 | 1.00 | 10 | 2.5 | 6.0 | 0.1 |

By carrying the experiment we got the following results.

V=22 kV

| &b / ° | n&l / pm | R_0 / 1/s |
|---|---|---|
| 5.2 | 51.1 | 4 |
| 5.3 | 52.1 | 22 |
| 5.4 | 53.1 | 47 |
| 5.5 | 54.1 | 91 |
| 5.6 | 55 | 133 |
| 5.7 | 56 | 129 |
| 5.8 | 57 | 148 |
| 5.9 | 58 | 181 |
| 6 | 59 | 196 |
| 6.1 | 59.9 | 177 |
| 6.2 | 60.9 | 206 |

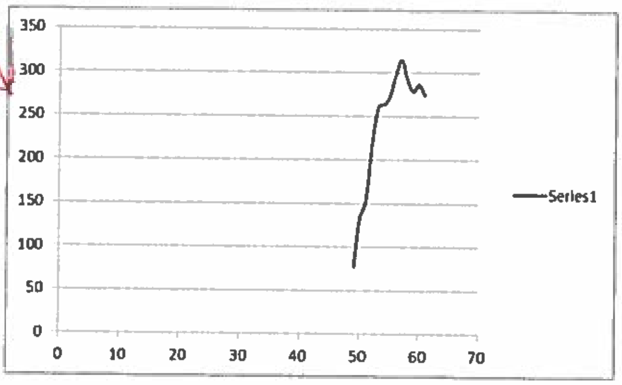
λ min= 50.7 pm




V=24 kV

| &b / ° | n&l / pm | R_0 / 1/s |
|---|---|---|
| 5 | 49.2 | 78 |
| 5.1 | 50.1 | 132 |
| 5.2 | 51.1 | 153 |
| 5.3 | 52.1 | 219 |
| 5.4 | 53.1 | 261 |
| 5.5 | 54.1 | 264 |
| 5.6 | 55 | 273 |
| 5.7 | 56 | 297 |
| 5.8 | 57 | 315 |
| 5.9 | 58 | 292 |
| 6 | 59 | 279 |
| 6.1 | 59.9 | 287 |
| 6.2 | 60.9 | 275 |

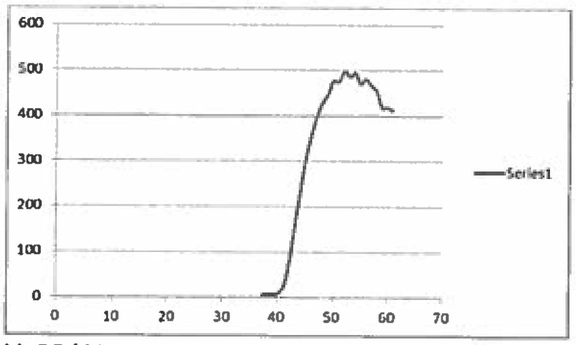
λ min=44.7 pm




V=26 kV

| &b / ° | n&l / pm | R_0 / 1/s |
|---|---|---|
| 4.5 | 44.3 | 34 |
| 4.6 | 45.2 | 82 |
| 4.7 | 46.2 | 149 |
| 4.8 | 47.2 | 194 |
| 4.9 | 48.2 | 260 |
| 5 | 49.2 | 319 |
| 5.1 | 50.1 | 331 |
| 5.2 | 51.1 | 321 |
| 5.3 | 52.1 | 365 |
| 5.4 | 53.1 | 371 |
| 5.5 | 54.1 | 409 |
| 5.6 | 55 | 376 |
| 5.7 | 56 | 371 |
| 5.8 | 57 | 367 |
| 5.9 | 58 | 375 |
| 6 | 59 | 379 |
| 6.1 | 59.9 | 369 |
| 6.2 | 60.9 | 361 |

λ min=41 pm



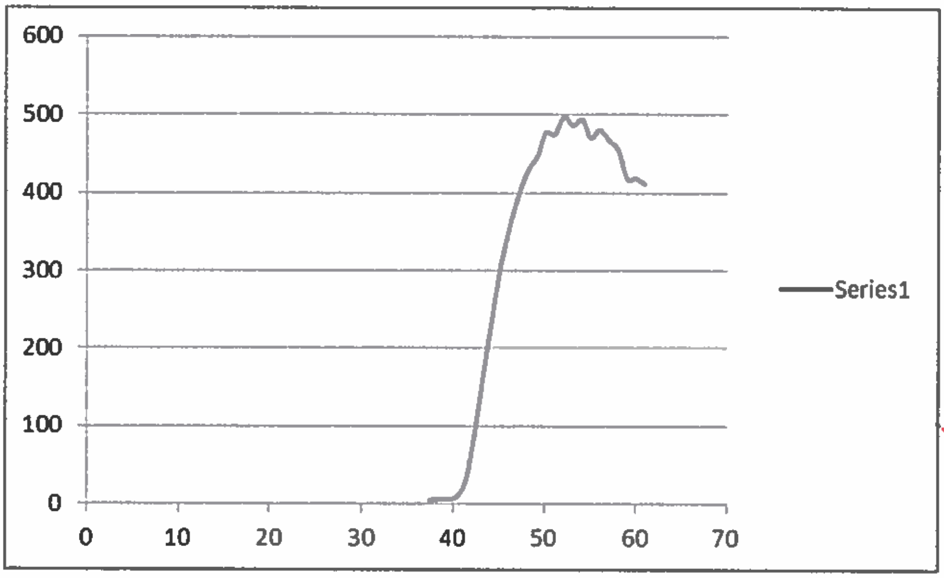

label graph & put all graphs together and all tables together

V=28 kV

| &b / ° | n&l / pm | R_0 / 1/s |
|---|---|---|
| 3.8 | 37.4 | 5.7 |
| 3.9 | 38.4 | 6.75 |
| 4 | 39.3 | 6.6 |
| 4.1 | 40.3 | 9.45 |
| 4.2 | 41.3 | 27 |
| 4.3 | 42.3 | 85.05 |
| 4.4 | 43.3 | 165.75 |

| | | |
|---|---|---|
| 4.5 | 44.3 | 242 |
| 4.6 | 45.2 | 306.8 |
| 4.7 | 46.2 | 357.6 |
| 4.8 | 47.2 | 399.05 |
| 4.9 | 48.2 | 429.4 |
| 5 | 49.2 | 447.05 |
| 5.1 | 50.1 | 476.6 |
| 5.2 | 51.1 | 474.6 |
| 5.3 | 52.1 | 497.35 |
| 5.4 | 53.1 | 486.3 |
| 5.5 | 54.1 | 493.9 |
| 5.6 | 55 | 470.15 |
| 5.7 | 56 | 480.7 |
| 5.8 | 57 | 467.25 |
| 5.9 | 58 | 454.95 |
| 6 | 59 | 417.85 |
| 6.1 | 59.9 | 418.65 |
| 6.2 | 60.9 | 411.4 |

λ min=38.7 pm



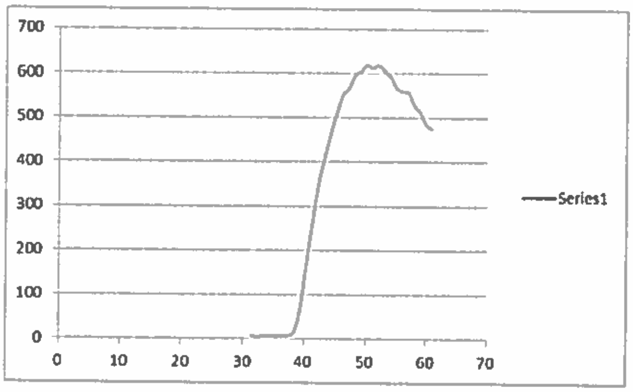

label & captions

V=30 kV

| &b / ° | n&l / pm | R_0 / 1/s |
|---|---|---|
| 3.2 | 31.5 | 8.3 |
| 3.3 | 32.5 | 5.9 |
| 3.4 | 33.4 | 8.5 |

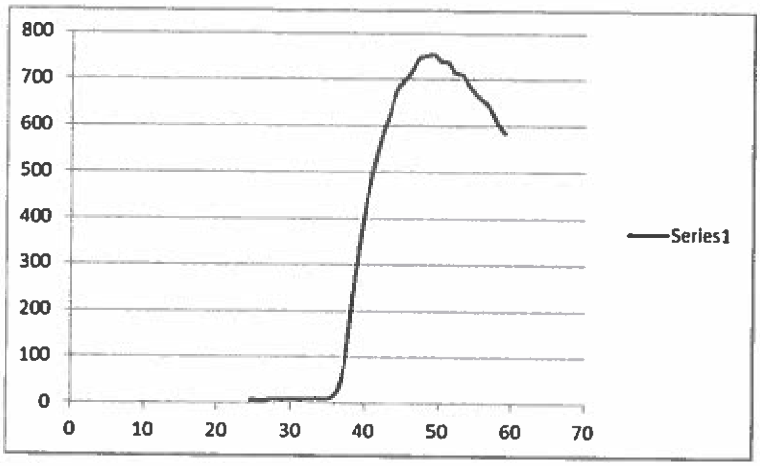
| | | |
|---|---|---|
| 3.5 | 34.4 | 8.5 |
| 3.6 | 35.4 | 7.7 |
| 3.7 | 36.4 | 8.2 |
| 3.8 | 37.4 | 8.9 |
| 3.9 | 38.4 | 17.1 |
| 4 | 39.3 | 61 |
| 4.1 | 40.3 | 158 |
| 4.2 | 41.3 | 255 |
| 4.3 | 42.3 | 344.3 |
| 4.4 | 43.3 | 407.5 |
| 4.5 | 44.3 | 462.5 |
| 4.6 | 45.2 | 509 |
| 4.7 | 46.2 | 550.1 |
| 4.8 | 47.2 | 566.3 |
| 4.9 | 48.2 | 595.8 |
| 5 | 49.2 | 605 |
| 5.1 | 50.1 | 618.5 |
| 5.2 | 51.1 | 612 |
| 5.3 | 52.1 | 618.2 |
| 5.4 | 53.1 | 604.8 |
| 5.5 | 54.1 | 592.7 |
| 5.6 | 55 | 568.8 |
| 5.7 | 56 | 558.5 |
| 5.8 | 57 | 556.6 |
| 5.9 | 58 | 527.4 |
| 6 | 59 | 510.7 |
| 6.1 | 59.9 | 485.3 |
| 6.2 | 60.9 | 474.2 |

λ min=35.1 pm




V=32 kV

| &b / ° | n&l / pm | R_0 / 1/s |
|---|---|---|
| 2.5 | 24.6 | 8.4 |
| 2.6 | 25.6 | 7.5 |
| 2.7 | 26.6 | 7.6 |
| 2.8 | 27.6 | 10.5 |
| 2.9 | 28.5 | 9.5 |
| 3 | 29.5 | 9.4 |
| 3.1 | 30.5 | 9.8 |
| 3.2 | 31.5 | 9.1 |
| 3.3 | 32.5 | 10.2 |
| 3.4 | 33.4 | 11 |
| 3.5 | 34.4 | 10.5 |
| 3.6 | 35.4 | 12.2 |
| 3.7 | 36.4 | 29.3 |
| 3.8 | 37.4 | 91.9 |
| 3.9 | 38.4 | 230.3 |
| 4 | 39.3 | 340.6 |
| 4.1 | 40.3 | 444 |
| 4.2 | 41.3 | 518.9 |
| 4.3 | 42.3 | 579.6 |
| 4.4 | 43.3 | 626.4 |
| 4.5 | 44.3 | 677.9 |
| 4.6 | 45.2 | 696.1 |
| 4.7 | 46.2 | 717.8 |
| 4.8 | 47.2 | 745.2 |
| 4.9 | 48.2 | 750.9 |
| 5 | 49.2 | 754.8 |
| 5.1 | 50.1 | 740.7 |
| 5.2 | 51.1 | 738.7 |
| 5.3 | 52.1 | 716.6 |
| 5.4 | 53.1 | 711.1 |
| 5.5 | 54.1 | 689.2 |
| 5.6 | 55 | 671.4 |
| 5.7 | 56 | 654.9 |
| 5.8 | 57 | 638.9 |
| 5.9 | 58 | 607.8 |
| 6 | 59 | 585.2 |
| 6.1 | 59.9 | 563.6 |
| 6.2 | 60.9 | 551 |




label captions

λ min=30.9 pm

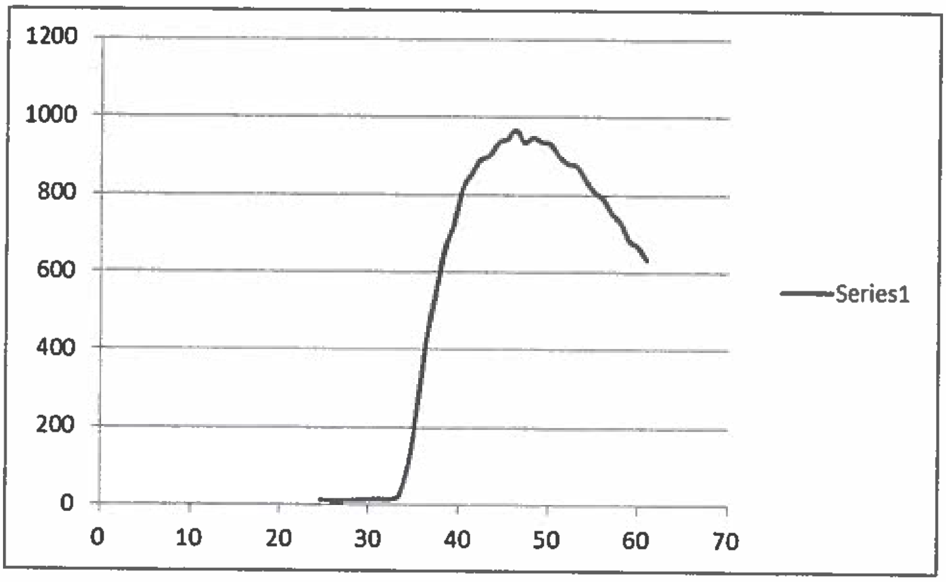
V=34 kV

| &b / ° | n&l / pm | R_0 / 1/s |
|---|---|---|
| 2.5 | 24.6 | 13.7 |
| 2.6 | 25.6 | 12.3 |
| 2.7 | 26.6 | 11 |
| 2.8 | 27.6 | 13 |
| 2.9 | 28.5 | 13.3 |
| 3 | 29.5 | 13.9 |
| 3.1 | 30.5 | 15.9 |
| 3.2 | 31.5 | 15.8 |
| 3.3 | 32.5 | 15.6 |
| 3.4 | 33.4 | 26.4 |
| 3.5 | 34.4 | 108.7 |
| 3.6 | 35.4 | 261.3 |
| 3.7 | 36.4 | 429.5 |
| 3.8 | 37.4 | 545.4 |
| 3.9 | 38.4 | 663 |
| 4 | 39.3 | 720.4 |
| 4.1 | 40.3 | 813.9 |
| 4.2 | 41.3 | 853.4 |
| 4.3 | 42.3 | 889.4 |
| 4.4 | 43.3 | 901.7 |

| | | |
|---|---|---|
| 4.5 | 44.3 | 934.1 |
| 4.6 | 45.2 | 943.1 |
| 4.7 | 46.2 | 966.5 |
| 4.8 | 47.2 | 934.6 |
| 4.9 | 48.2 | 947.3 |
| 5 | 49.2 | 935.2 |
| 5.1 | 50.1 | 930.6 |
| 5.2 | 51.1 | 898.7 |
| 5.3 | 52.1 | 880.1 |
| 5.4 | 53.1 | 872.8 |
| 5.5 | 54.1 | 837.1 |
| 5.6 | 55 | 808 |
| 5.7 | 56 | 789.9 |
| 5.8 | 57 | 752.5 |
| 5.9 | 58 | 727.6 |
| 6 | 59 | 681.8 |
| 6.1 | 59.9 | 667.6 |
| 6.2 | 60.9 | 633.5 |

λ min=30 pm

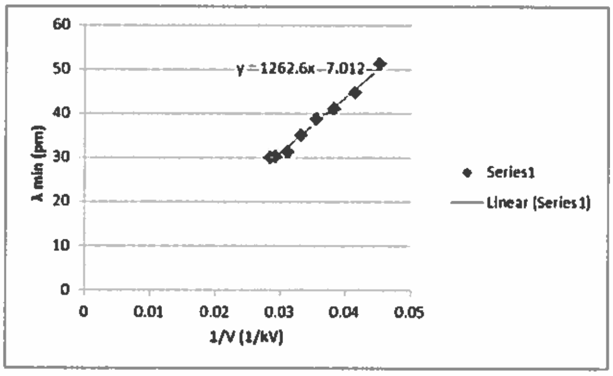
label & caption




Then when we plot the λ min values that we extracted from the previous graphs we get the following plot:

| 1/V | &l_min / pm |
|---|---|

| | |
|---|---|
| 0.045454545 | 51.3 |
| 0.041666667 | 44.7 |
| 0.038461538 | 41 |
| 0.035714286 | 38.7 |
| 0.033333333 | 35.1 |
| 0.03125 | 31.3 |
| 0.029411765 | 30.2 |
| 0.028571429 | 30 |




The slope of this curve =1262.6 pmkV.The curve is linear as the correlation coefficient=0.994.

From the slope value we deduce that hc/e=1262.6 pmkV,where h is the Planck's constant ,c is the speed of light=3E8 m/s and e is the electron charge =1.6E-19

Thus we find that Planck's constant(h)=6.73E-34 J.s.The actual value as we know is 6.63E-34 J.s.The difference between the two readings is 1.49% which is very small and could be derived from various sources of error.We found the Planck's constant from this experiment using just the dependency of the λ min on the potential.The minimum wavelength was extracted from the graphs by just locating the lowest value of wavelengths for the general x-ray.

**Attenuation**

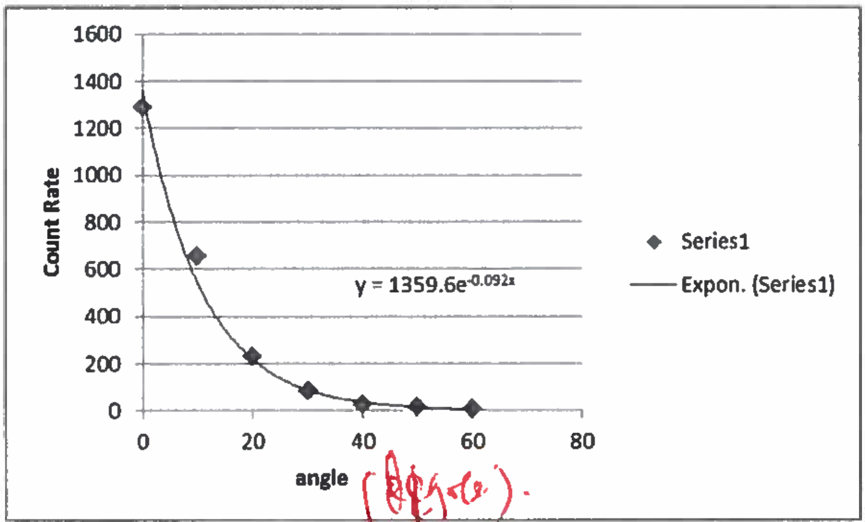
In this experiment we will examine the attenuation of the x-ray in two criteria .The first open is the intrinsic properties of the material which is verified by changing the material itself or by changing the thickness of the material.

In this experiment we remove that sample from the holder and put instead slab on the side in order to create a direct blockage to the X-ray path.

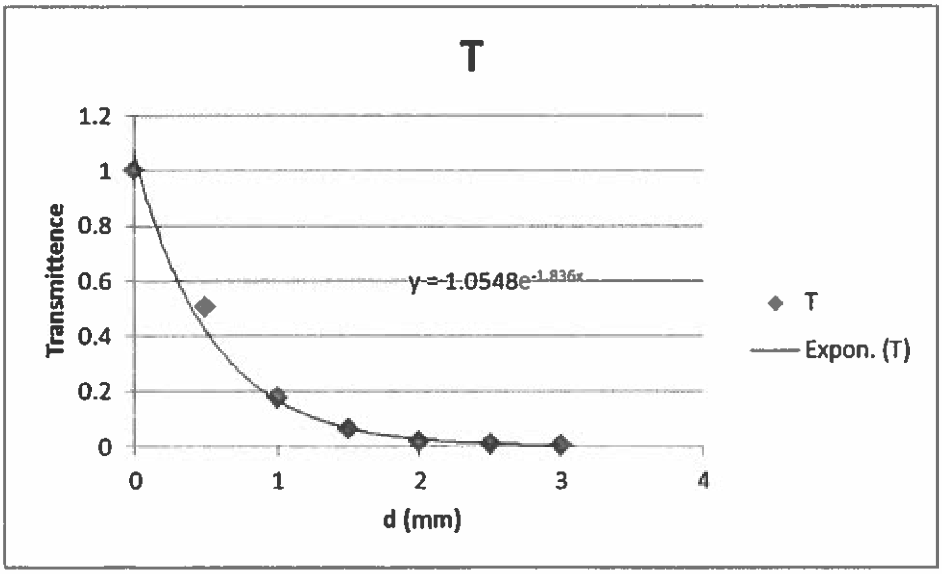
a)Attenuation as a function of thickness

In this experiment we will rotate the slab automatically thus we set $\Delta\beta = 0$.The intervals here are also longer than usual in order to allow for the radiation counts to stabilize ($\Delta t$=100s).The angles means differing thickness mediums.So changing angle is a quick way for changing the thicknesses of the same material.The slabs used in these experiments are made of aluminum. The voltage=21mkV and the current =0.05 mA .After we took the readings the results were as follows:

| angle | Thickness | R |
|---|---|---|
| 0 | 0 | 1289 |
| 10 | 0.5 | 653 |
| 20 | 1 | 230 |
| 30 | 1.5 | 83 |
| 40 | 2 | 25 |
| 50 | 2.5 | 13 |
| 60 | 3 | 7 |




T=Ro/R where Ro is the count rate at zero thickness (corresponds to angle).We get this graph for the transmittance vs. thickness graph.



From this graph we can deduce that the attenuation coefficient is 1.836/mm or 18.36/cm.The value expected from the manual is 14.2/cm.The diffrecne is 22.7% which is expected due to the inaccuracy of the readings (stochastic nature) and also it is due partly to the slab inaccuracy.However, the positive point is that we are nothing a clear exponential relation between the thickness and the transmitted rays which means that the material have constant attenuation and the relation is exponential as predicted by theory.

b)Attenuation as a function of material

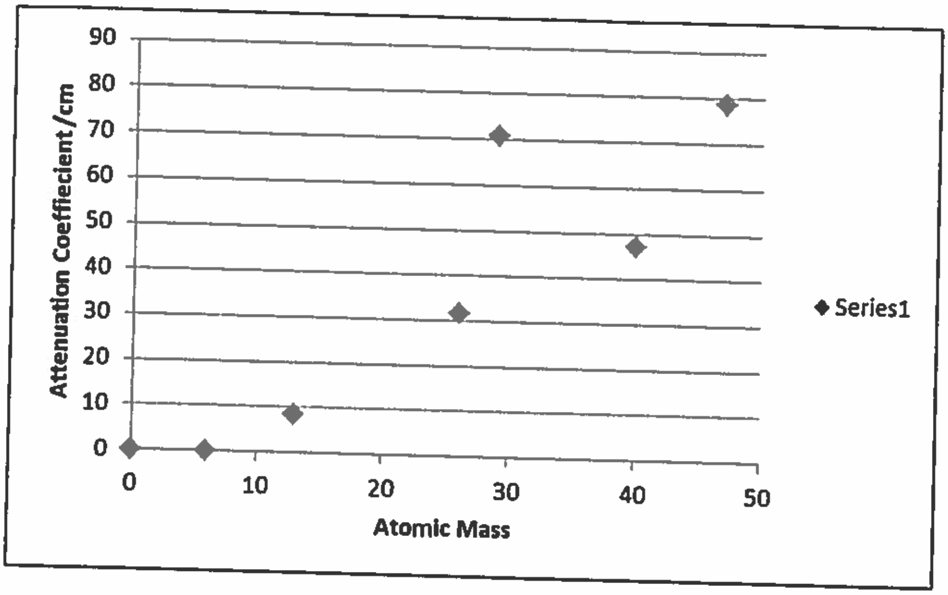
In this experiment we will use instead a slab of several materials that have correspondence with the angle.We will use V=30 kV, I=0.02 mA , Δβ=0 and Δt=30,300s.The specifications of this experiment is shown here:

| Absorber | $Z$ | $\frac{I}{mA}$ | $\frac{\Delta t}{s}$ |
|---|---|---|---|
| none | | 0.02 | 30 |
| C | 6 | 0.02 | 30 |
| Al | 13 | 0.02 | 30 |
| Fe | 26 | 1.00 | 300 |
| Cu | 29 | 1.00 | 300 |
| Zr | 40 | 1.00 | 300 |
| Ag | 47 | 1.00 | 300 |

The time intervals this time interval is 30 for the first 3 materials and then 300 for the rest.We get the following results:

| angle | Z | R |
|---|---|---|
| 0 | 0 | 2256 |
| 10 | 6 | 2239 |
| 20 | 13 | 1470 |
| 30 | 26 | 467 |
| 40 | 29 | 65 |
| 50 | 40 | 215 |
| 60 | 47 | 44 |

Then when finding the transmittance and the attenuation coefficient we get the following graph of attention coefficient vs. atomic mass since the thickness of each slab is fixed to be 0.05 cm.




v. good.

This figure matches the one suggest in the manual and shows of sort of manner but we cannot relate up to what I know here between the attenuation coefficient and the atomic mass directly since there are several factors intriguing in between.For Z more than 40, there are some excitations cannot happen any more in the atomic structure which drives the attenuation to fall significantly but the trend seems to continue with lower values.

## Conclusion

This experiment was stiff with details and information that concerns the relation that we can deduce from the XRD and most importantly the properties of XRD itself .These properties included the energy spectrum ,Bragg reflection ,attenuation and finally the relation with the energy and the wavelength from which we can determine the Planck's constant. From here, there were several experiments performed in order to prove the validity of our assumptions. From these experiments we concluded several facts.First the Bragg reflection dependency on the path difference and the at the characteristics x-rays are produced for certain positions deepening on the path difference. Secondly, we found that the characteristic x-ray positions does not depend on the potential nor the current.Then we verified that the intensity of the x-ray depends on the applied current.Then we verified the dependency of the wavelength on the potential and from there we show the validity of planck's constant to a considerably high accuracy .Then we saw that the attenuation of x-rays depends on the thickness other material exponentially and we showed also that the dependence on the material type have several factors that cannot but as Z increase the general trend is that the transmitted radiation reduces .All of these exciting properties are determined only by a single point which is the characteristic x-rays which is a quantum process result inside the atom. This can show us the Importance of the energy states transfers.