King Fahd University of Petroleum and Minerals

Department of Physics

Department Course Report

Course title:	**SENIOR PHYSICS LAB**
Course number:	**PHYS 403**
Term:	**161**
# of sections:	**1**
Instructor/ coordinator name:	**Akhtar A. Naqvi**

Grade	# students	% of students	grade range / 100 From	grade range / 100 To
A^+	0		80	100
A	4		76	79
B^+	2		72	75
B	1		67	71
C^+	0		60	66
C	0		53	59
D^+	0		47	52
D	0		41	46
F	0		< 41	
W	0			
WP	0			
WF	0			
DN	0			
Z	0			
AU	0			
IC	0			
Total	7	100		
Course Average/100	75			
Course Standard Deviation/100	4.00			
Course Grade Average	3.57			

Course grade average $= \frac{4^* A^+ + 3.75^* A + 3.5^* B^+ + 3^* B + 2.5^* C^+ + 2^* C + 1.5^* D^+ + D}{A^+ + A + B^+ + B + C^+ + C + D^+ + D}$

$(4(0) + 3.75(4) + 3.5(2) + 3(1) + 2.5(0) + 2(0) + 1.5(0) + 1.(0))/(4+2+1) = 25/7 = 3.57$

Include the following table for each "IC" grade

Student's ID #	N/A
Student's name	
Justification for giving "IC" grade	
Requirements to remove "IC" Grade	

Attach the following documents:

document	# of documents
Phys403 Grading Policy	1
Phys403 Lab. Schedule	1
Phys403 PP Presentation Schedule	1
Phys403 Report Format	1
Phys403 PP Presentation Format	1
Phys403 PP Presentation Evaluation criteria	1
Samples-Phys 403 Graded Reports	-
Samples-Phys 403 PP Presentations	-

Grading Criteria Phys403 T161

i) **Lab. Reports** = 75 %

ii) **PP** Presentations **of Exp*.** = 25 %

*Exp. to be chosen by the student for PP Presentation.

Phys403 Lab. Schedule T161

Choose any 4 Experiments out of the following 5 experiments

Exp. #	Exp. Title	Week
1	Optical Pumping	3
2	Nuclear Magnetic Resonance	3
3	Electron Spin Resonance	3
4	X-Ray Diffraction	3
5	Diode Laser Studies	3
	PP Presentation of Reports	14^{th} Week

PP Presentation Schedule Phys403-T161

Mon. Jan. 2, 2017 Room 4-106 from 9:00 am -12:00 pm

S#	Student Name	ID	NMR	Optical Pumping	Diode Laser	XRD	ESR
1	ALSHAMMARY, MOHAMMED O.	201143050	√				
2	ALZAHRANI, MUHANNAD K.	201151030				√	
3	ALMALEKI, HESHAM A.	201175730			√		
4	HARIRI, ABDULKARIM O.	201228600		√			
5	ALALAWI, SHABEEB Y.	201246360					√
6	ALJAMA, AHMAD H.	201257400		√			
7	ALNIMASI, OMAR J.	201332050			√		
8							

Phys403 Report Format T161

Phys503 Report Evaluation Criteria (Max. Pages = 15, Total Points = 70)

(Report Contents and associated grade points)

☐ **Title page**
- **Title of the experiment**
- **Course name and term**
- **Name of student and ID number**
- **Name of supervisor**
- **Date of submission**

☐ **Table of contents page**

☐ **Abstract page (maximum 1/2 page)** **5/70**
- Brief summary of the technique used and main findings.

☐ **Introduction (maximum 2 pages)** **15/70**
- Background including, basic principle and theory, a brief review of literature.
- Objectives

☐ **Experimental details (maximum 4 pages)** **20/70**
- Description of equipment
- Sample preparation
- Description of methods used.

☐ **Results and Discussion (maximum 6 pages)** **20 /70**
- States the results of the research.
- Data analysis
- Discussion of results

☐ **Conclusion (maximum 1/2 page)** **5/70**
- Summary of results and main findings.

☐ **References (maximum 1 pages)** **3/70**

☐ **Overall Impression** **2/70**

Phys403 T161-PP Presentation Format

Phys403 PP Presentation Contents (Max. Number of Slides-15)

- ☐ **Project Title , student's name, supervisor's name**
- ☐ **Presentation Outline (max 1 slide)**
  - Introduction
  - Theoretical Background
  - Experimental
  - Results and Discussion
  - Conclusion
- ☐ **Introduction (max 3 slides)**
  - Brief review of the work and literature.
- ☐ **Theoretical Background (max 2 slides)**
  - Basic principle
- ☐ **Experimental procedure (max 3 slides)**
  - Equipment used
  - Sample fabrication
  - Experimental measurement
- ☐ **Results and Discussion (max 5 slides)**
  - Data Analysis and Interpretation
- ☐ **Conclusion (max 1 slide)**

Evaluation Criteria of Phys403 T161-PP Presentations (Total 30 Points)

- **Subject knowledge** — 15/30
  - Correctness of the slides
  - Question and answer
  - Subject understanding

- **Clarity** — 6/30
  - Graphics
  - Logical sequence of presentation

- **Delivery** — 4/30
  - Eye contact and Body language
  - Language and Sound level

- **Time management** — 3/30
  - Not exceeding the allocated time
  - Balanced time distribution among topics

- **Overall Impression** — 2/30

Samples of Graded Reports

Al-Maleki

XRD

Phys403 Report Format T161

Exp #1

Phys403 Report Evaluation Criteria (Total Points =75)

(Report Contents and associated grade points)

- ☐ **Title page** — **2/75**
  - **Title of the experiment**
  - **Course name and term**
  - **Name of student and ID number**
  - **Name of supervisor**
  - **Date of submission**

2

- X ☐ **Table of contents page**
- ✓ ☐ **Abstract** — 3 — **4/75**
  - Brief summary of the technique used and main findings.
- ☐ **Introduction** — 5 — **10/75**
  - Background including, basic principle and theory, a brief review of literature.
- ✓ ☐ Objectives — 5 — **5/75**
- ☐ **Experimental details** — 18 — **20/75**
  - ✓ Description of equipment
  - ✓ Sample preparation
  - ✓ Description of methods used.
- ✓ ☐ **Results and Discussion** — 22 — **25 /75**
  - ✓ States the results of the research.
  - ✓ Data analysis
  - ✓ Discussion of results
- ✓ ☐ **Conclusion** — 5 — **5/75**
  - Summary of results and main findings.
- ☐ **References** — 0 — **4/75**

60

60/75

E

Exp #1

King Fahd University of Petroleum and Minerals

College of Sciences

Department of Physics

Phys 403 – Senior Physics Laboratory

Report Title: **X-Ray Diffraction**

by

Hesham Almaleki

201175730

❖ Abstract

It should be Summary of your experiment performed.

Under the X-Ray Diffraction, I will be performing three different experiments. The titles of these experiments are:

1. Fine structure of the characteristic x-radiation of a molybdenum anode.
2. Duane-Hunt relation and determination of Planck's constant.
3. Bragg reflection diffraction of x-rays at a monocrystal.

❖ Objective and Tasks

A. Fine structure of the characteristic x-radiation of a molybdenum anode.

- To investigate the fine structure of the characteristic x-radiation of molybdenum by means of Bragg reflection at an NaCl monocrystal in the fifth diffraction order.
- Identifying the characteristic Ka, Kb and Kg lines.
- Resolving the fine structure of the Ka line as a line doublet and determining the wavelength interval Dl within the doublet.

B. Duane-Hunt relation and determination of Planck's constant.

- To determine the limit wavelength lmin of the bremsstrahlung continuum as a function of the high voltage U of the x-ray tube.
- To confirme the Duane-Hunt relation.
- To determine Planck's constant.

C. Bragg reflection diffraction of x-rays at a monocrystal.

- To investigate Bragg reflection at an NaCl monocrystal using the characteristic x-ray radiation of molybdenum.
- Determining the wavelength for the characteristic Ka and Kb x-ray radiation of molybdenum.
- Confirming Bragg's law of reflection.
- To verify the wave nature of x-rays.

❖ Apparatus

All of the three experiments have a common apparatus with little differences, of course.

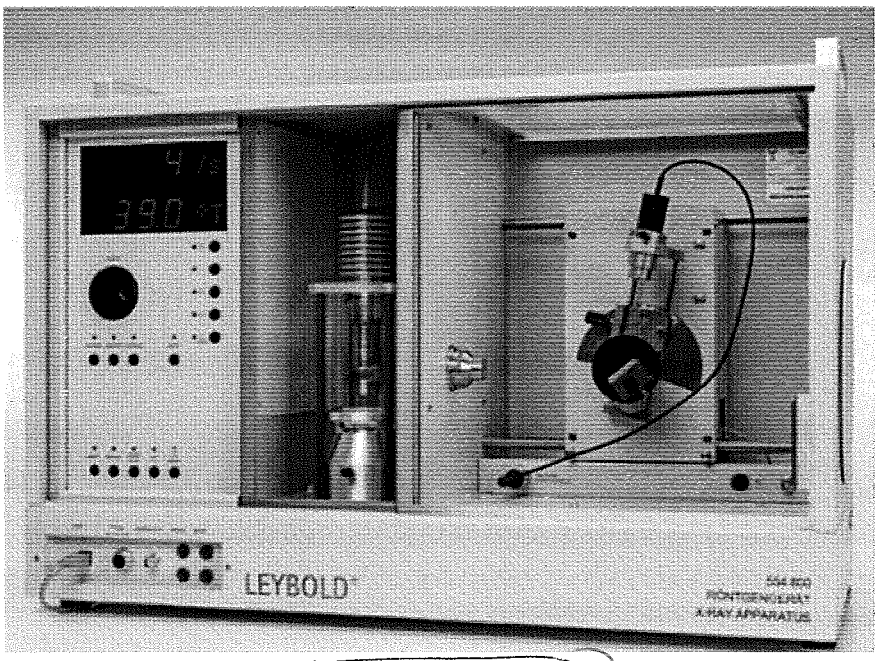


Figure 1: X-ray apparatus.

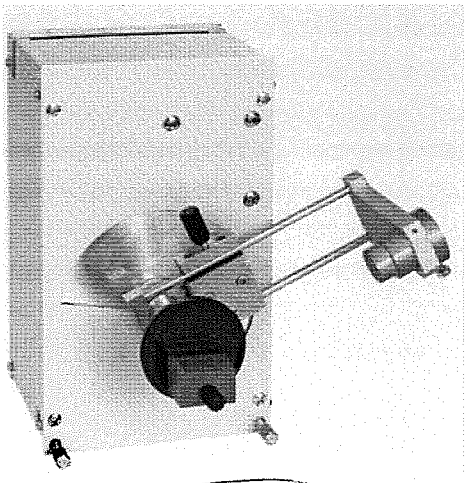


Figure 2: Goniometer.

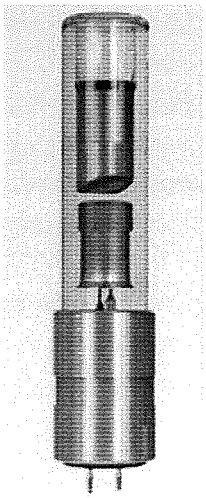
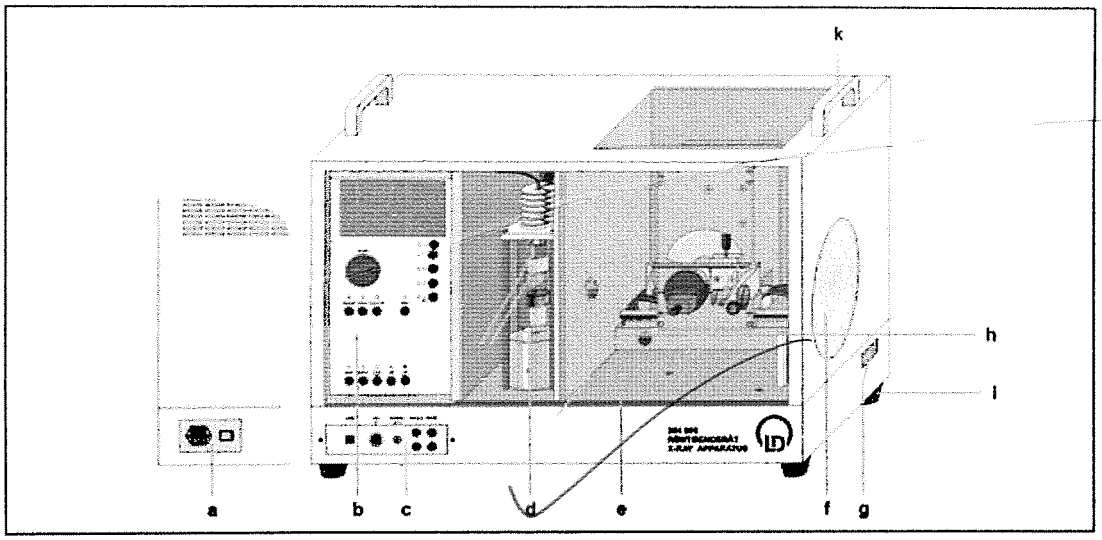
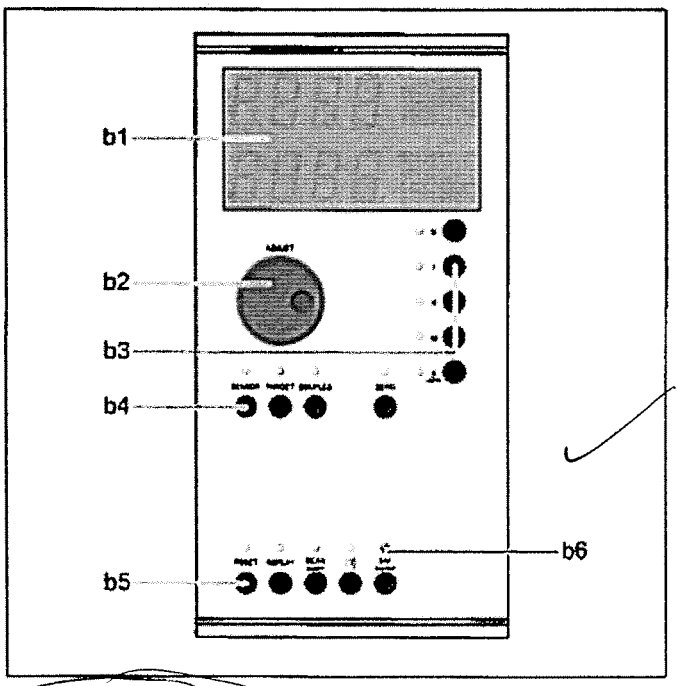


Figure 3: X-ray tube.



a Mains power panel
b Control panel
c Connection panel
d Tube chamber (with X-ray tube Mo)
e Experiment chamber (here with goniometer)
f Fluorescent screen
g Free channel
h Lock
i Feet
k Carrying handles

Figure 4: Schematic drawing of the X-ray apparatus.



b1 Display field
b2 Knob
b3 Parameter selector keys
b4 Scan-mode keys
b5 Operational keys
b6 High-voltage indicator lamp

Figure 5: Control Panel

- XRD apparatus is simply consist of a source, a sample, and a detector.
- The source is x-ray emitter. It emits x-ray by hitting electrons with the (Molybdenum) atoms.
- The sample used is (NaCl). It is mounted on the Goniometer.
- Goniometer is the device that changes the angle of rotation of NaCl sample.
- The type of detector is GM-Tube.
- The x-ray apparatus is connected to a computer with a Windows-7 operating system.

- **Safety Regulations:**

The x-ray apparatus fulfills all regulations governing an x-ray apparatus and fully protected device for instructional use and is type approved for school use in Germany (NW
807/97 Rö). The built-in protection and screening measures reduce the local dose rate outside of the x-ray apparatus to less than 1 mSv/h, a value which is on the order of magnitude of the natural background radiation.

- Before putting the x-ray apparatus into operation inspect it for damage and to make sure that the high voltage is shut off when the sliding doors are opened.
- Keep the x-ray apparatus secure from access by unauthorized persons.
- Do not allow the anode of the x-ray tube Mo to overheat.
- When switching on the x-ray apparatus, check to make sure that the ventilator in the tube chamber is turning.
- Do not block the target arm and sensor arm of the goniometer and do not use force to move them.

❖ Experiments

I- Fine structure of the characteristic x-radiation of a molybdenum anode.

- **Theory:**

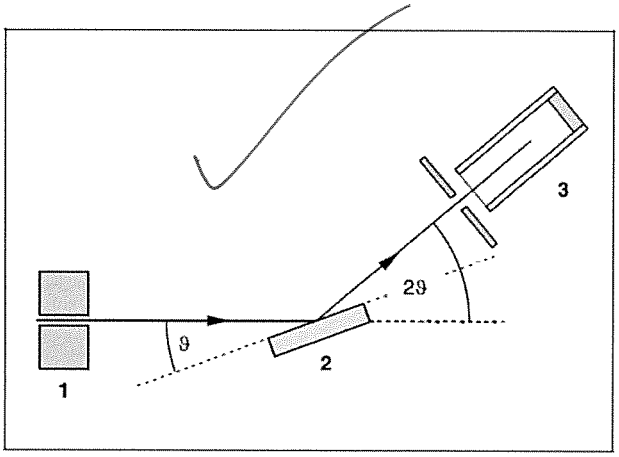


Figure 6: Diagram showing the diffraction of x-rays at a monocrystal
1 collimator, 2 monocrystal, 3 counter tube.

$$\Delta\vartheta = \frac{n \cdot \Delta\lambda}{2 \cdot d \cdot \cos\vartheta}$$

Where:

n: diffraction order.

$d = 282.01$ pm: lattice plane spacing of NaCl.

$\Delta\vartheta$ = angular spacing. (see Figure 7)

$\Delta\lambda$ = The wavelength interval of two lines

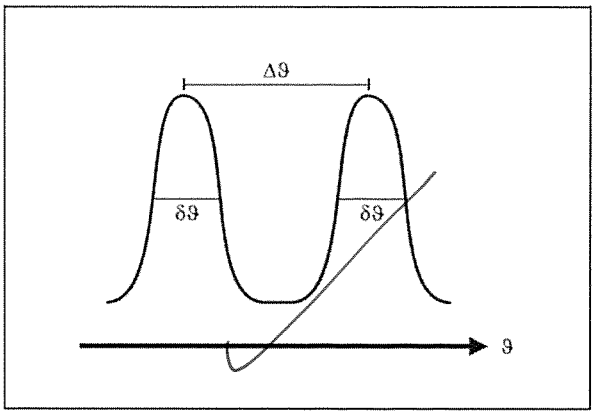


Figure 7: Definition of the angular width $d\vartheta$ and the angular spacing $\Delta\vartheta$ of two intensity maxima.

The values of the characteristic lines, K_α and $K_\beta + K_\gamma$ that appear in the first order diffraction are listed in the following table:

	Literature value
Line doublet	λ/pm
K_α	71.08
$K_\beta + K_\gamma$	63.09

But for the fifth order diffraction the values are as follows:

	Literature value
Line doublet	λ/pm
$K_{\alpha 1}$	70.93
$K_{\alpha 1}$	71.36
K_β	63.26
K_γ	62.09

Setup:

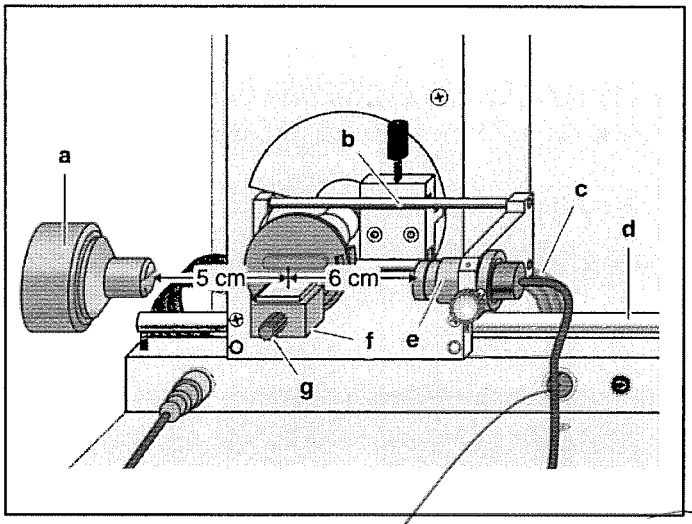


Figure 8: Experiment setup in Bragg configuration.

1- Connect the RS-232 output to the serial interface on the PC (COM1) using the 9-pin V.24 cable (included with the x-ray apparatus).
2- Install the collimator in the collimator mount (a).
3- Attach the goniometer to guide rods (d).
4- Make the distance from the slit diaphragm of the collimator to the target arm to be 5 cm.
5- Connect ribbon cable (c).
6- Remove the protective cap of the end-window counter, place the end-window counter in sensor seat (e).
7- Connect the counter tube cable to the socket marked GM-TUBE.
8- Set the distance between the target arm and the slit diaphragm of the sensor seat to around 6 cm by moving the sensor holder (b),
9- Mount the target holder (f) with target stage.
10- Place the NaCl crystal flat on the target substrate, and raise the target stage with crystal all the way to the stop.
11- Tighten the knurled screw.
12- Adjust the mechanical zero position of the Goniometer.

▪ Procedure:

- Start the software "X-ray Apparatus", check to make sure that the apparatus is connected correctly.
- Set the tube high voltage U = 35 kV, the emission current I = 1.00 mA and the angular step width $\Delta\beta = 0.1^{\circ}$.
- Press the COUPLED key for 2ϑ coupling of target and sensor.

a) First order of diffraction:

- Set the lower limit of the target angle to 5.5° and the upper limit to 8.0°.
- Set the measuring time per angular step to $\Delta t = 10$ s.
- Start measurement and data transfer to the PC by pressing the SCAN key.
- Save the measurement.

b) Fifth order of diffraction:

- Set the lower limit of the target angle to 32.5 and the upper limit to 40.5.
- Set the measuring time per angular step to $\Delta t = 400$ s.
  (Note: In order to obtain a satisfactory statistical accuracy, the measurement duration will be long. The total measuring time is 9 h.)
- Start measurement and data transfer to the PC by pressing the SCAN key.
- Save the measurement.

- **Data Analysis:**

First order diffraction

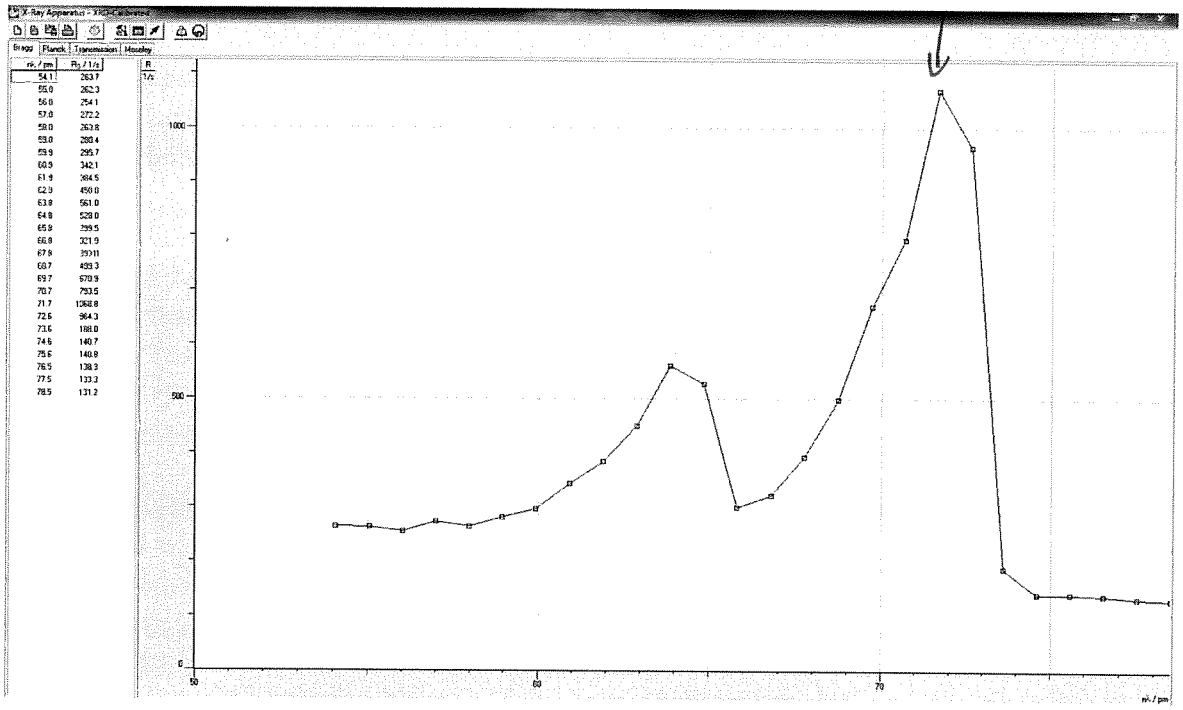


Figure 9: Diffraction spectrum of x-rays in Bragg reflection in the first order at an NaCl monocrystal Parameters: $U = 35$ kV, $I = 1$ mA, $\Delta t = 10$ s.

- From Figure 9,

  $K_\alpha = 71.7$ (λ/pm)

  $K_\beta + K_\gamma = 63.8$ (λ/pm)

  thus, $\Delta\lambda = 71.7 - 63.8 = 7.9$ (pm)

  the theoretical value is $\Delta\lambda = 71.08 - 63.09 = 7.99$ (pm)

- The percentage difference $= \frac{7.99 - 7.9}{7.99} \times 100 =$ **1.13 %**

Second order diffraction:

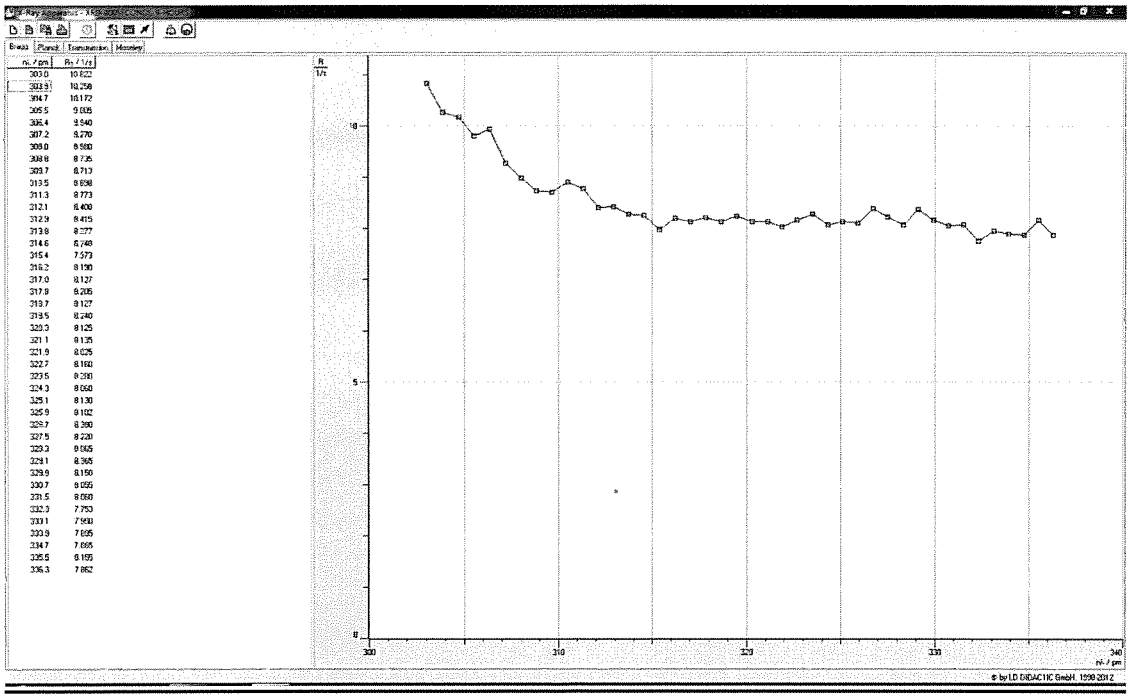


Figure 10: Diffraction spectrum of x-rays in Bragg reflection in the fifth order at an NaCl monocrystal Parameters: $U = 35$ kV, $I = 1$ mA, $\Delta t = 400$ s.

Why ??

- As we can see from Figure 10, there are no peaks appear in the curve of the fifth order diffraction.
- I will mention the source of error in the conclusion section.

II- Duane-Hunt relation and determination of Planck's constant.

- **Theory:**

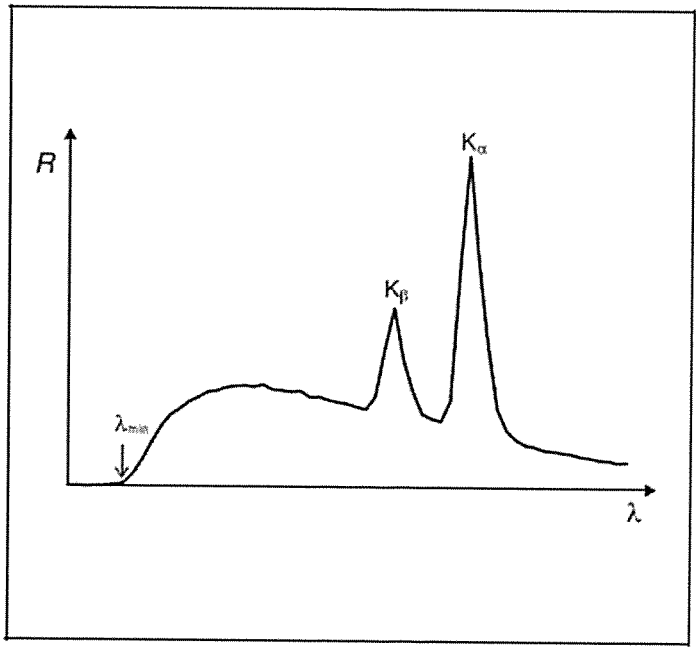


Figure 11: Emission spectrum of an x-ray tube with the limit wavelength lmin of the bremsstrahlung continuum and the characteristic Ka and Kb lines.

$$\lambda = \frac{c}{v}$$

$$E_{max} = h \,.\, v_{max}$$

$$E = e \,.\, U$$

$$v_{max} = \frac{e}{h} \,.\, U$$

$$\lambda_{min} = \frac{h \,.\, c}{e} \frac{1}{U}$$ (Duane and Hunt's law)

$$A = \frac{h \,.\, C}{e}$$

Where:

$c = 2.9979 \times 10^8$ (m/s): velocity of light.
h (*J . S*): Planck's constant.
$e = 1.6022 \times 10^{-19}$ C: elementary charge.
$\lambda = 2 \times d \times \sin \vartheta$

Setup:

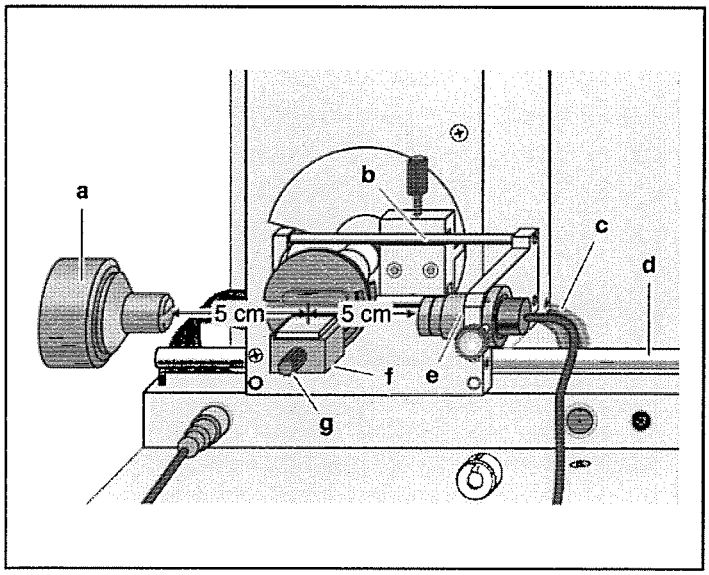


Figure 12: Experiment setup in Bragg configuration.

1- Connect the RS-232 output to the serial interface on the PC (COM1) using the 9-pin V.24 cable (included with the x-ray apparatus).
2- Install the collimator in the collimator mount (a).
3- Attach the goniometer to guide rods (d).
4- Make the distance from the slit diaphragm of the collimator to the target arm to be 5 cm.
5- Connect ribbon cable (c).
6- Remove the protective cap of the end-window counter, place the end-window counter in sensor seat (e).
7- Connect the counter tube cable to the socket marked GM-TUBE.
8- Set the distance between the target arm and the slit diaphragm of the sensor seat to around 5 cm by moving the sensor holder (b),
9- Mount the target holder (f) with target stage.
10- Place the NaCl crystal flat on the target substrate, and raise the target stage with crystal all the way to the stop.
11- Tighten the knurled screw.
12- Adjust the mechanical zero position of the Goniometer.

- **Procedure:**

- Start the software "X-ray Apparatus", check to make sure that the apparatus is connected correctly.
- Set the tube high voltage U = 22 kV, the emission current I = 1.00 mA, the measuring time per angular step $\Delta t = 30$ s and the angular step width $\Delta\beta = 0.1^0$.
- Press the COUPLED key to activate 2ϑ coupling of target and sensor and set the lower limit of the target angle to 5.2^0 and the upper limit to 6.2^0.
- Check if the machine need a calibration or not.
- Start measurement and data transfer to the PC by pressing the SCAN key.
- Repeat the procedure as in the following table:

$\frac{U}{kV}$	$\frac{I}{mA}$	$\frac{\Delta t}{s}$	$\frac{\beta_{min}}{grd}$	$\frac{\beta_{max}}{grd}$	$\frac{\Delta\beta}{grd}$
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

- Save the measuremens.
- Click the right mouse button and select the command "Best-fit Straight Line" in the diagram.
- Mark the curve ranges to which you want to fit a straight line to determine the limit wavelength λ_{min} using the left mouse button.
- Save the evaluations.
- Click on the register "Planck"to get further evaluation of the limit wavelength λ_{min} obtained in this experiment.
- Click the right mouse button, fit a straight line through the origin to the curve $\lambda_{min} = f(1/U)$ and read the slope A form the bottom left corner of the evaluation window.

- **Data Analysis:**

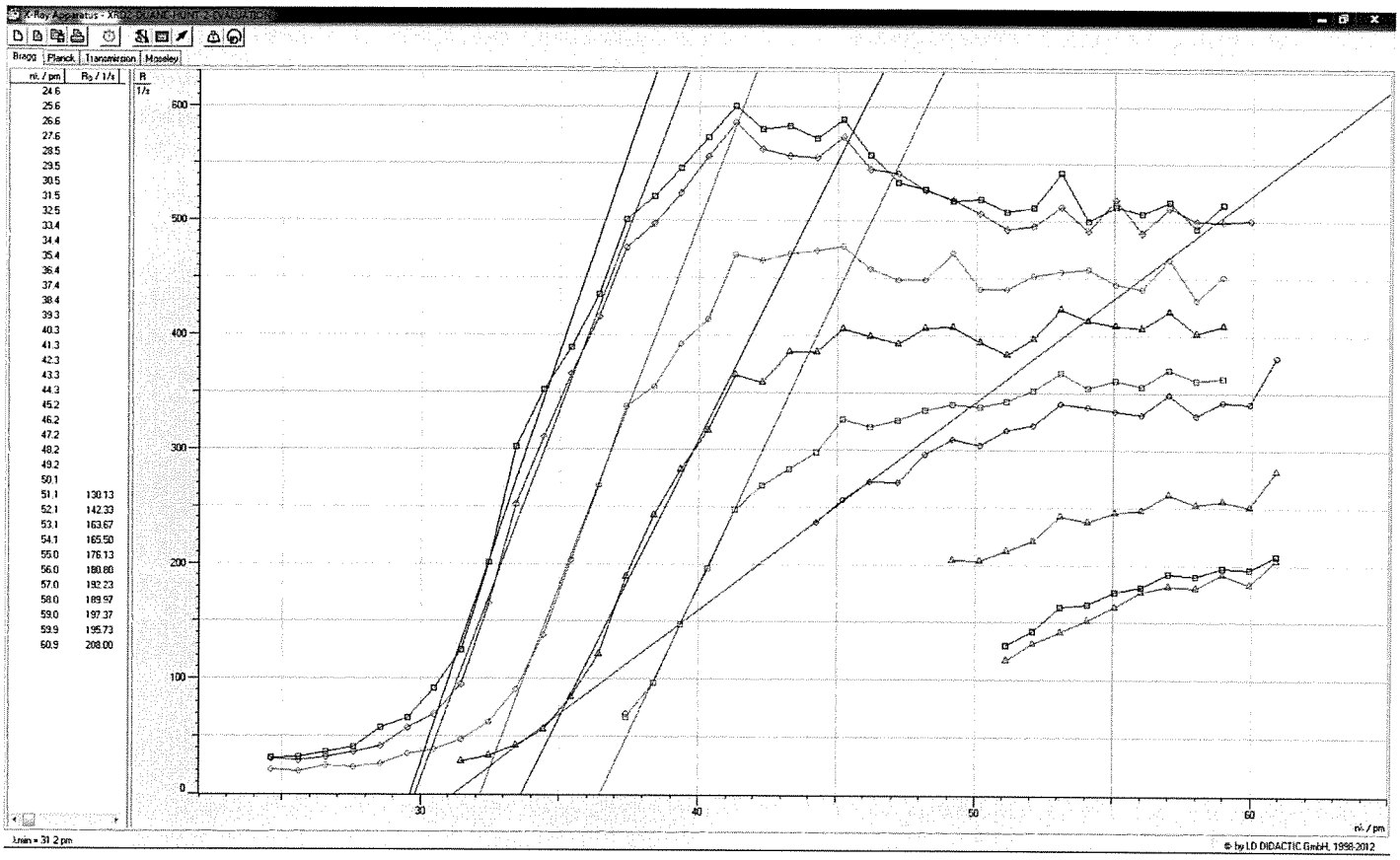


Figure 13: Sections from the diffraction spectra of x-radiation for the tube high voltages $U = 22$, 24,26, 28, 30, 32, and 35 kV (from right to left) with best-fit straight line for determining the limit.

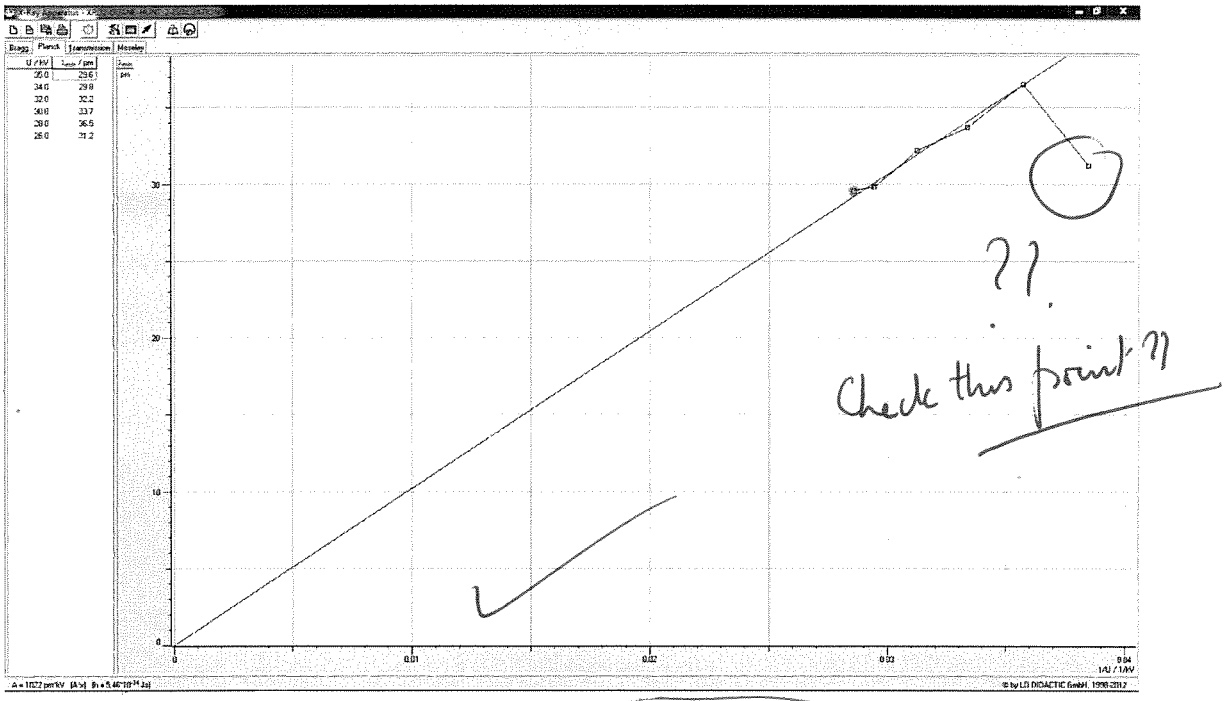


Figure 14: Evaluation of the data λ_{min} = f (1/U) for confirming the Duane-Hunt relation and determining Planck's constant.

Why ?

- What I have noticed is that some curves are not accurate, but those with a time interval of 10 seconds are much better and accurate than those with time interval of 20 or 30 seconds.
- When the lower limit changes the x-axes of the curves changes. It is shifted to the left when we decrease the lower limit. ??
- When the voltage increases, the curve is then shifted upward.
- From Figure 14, slope =1022 (pm * Kv), and h = 5.46x10-34 (J*s)
- The percentage difference = $\frac{6.63x10^{-34} - 5.46x10^{-34}}{6.63x10^{-34}}$ x100 = **17.6 %**

III- Bragg reflection: diffraction of x-rays at a monocrystal

- **Theory:**

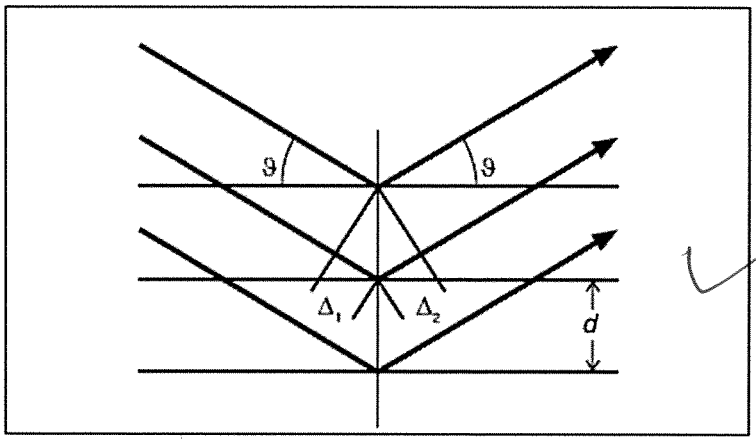


Figure 15: Diagram of the reflection of x-rays at the lattice planes of a monocrystal.

where:

Δ_1, Δ_2: path differences.
ϑ: glancing angle.
d: spacing of lattice planes

- Constructive interference arises in the rays reflected at the individual lattice planes when their path differences Δ are integral multiples of the wavelength.
  $\Delta = n \times \lambda$, $n = 1, 2, 3, \ldots$
- The total path difference of the incident and reflected rays with the angle ϑ is:
  $\Delta = 2 \times d \times \sin \vartheta$.
- By combining the two previous equations we get the Bragg's law of reflection:
  $n \times \lambda = 2 \times d \times \sin \vartheta$.

n	$\vartheta(K_\alpha)$	$\vartheta(K_\beta)$
1	7.24°	6.42°
2	14.60°	12.93°
3	22.21°	19.61°

This table represents the glancing angles ϑ of the characteristic x-ray radiation of molybdenum for diffraction at an NaCl monocrystal from the first diffraction order up to the third order.

- **Setup:**

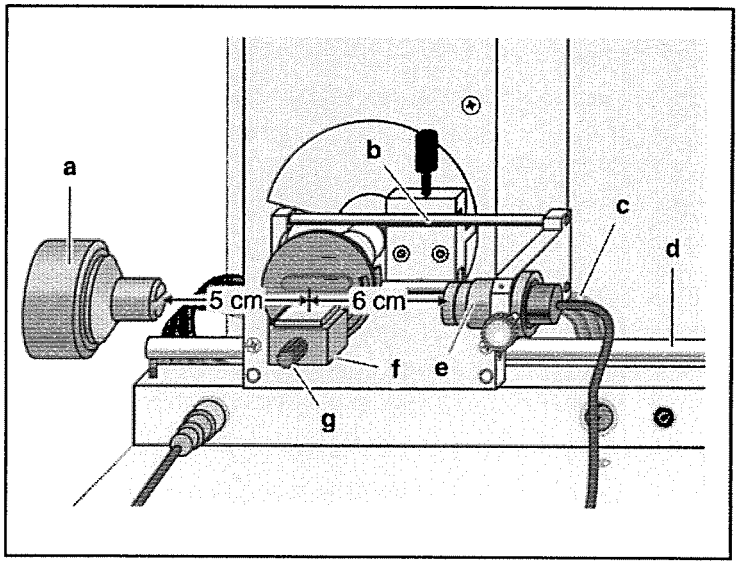


Figure 16: Experiment setup in Bragg configuration.

1- Connect the RS-232 output to the serial interface on the PC (COM1) using the 9-pin V.24 cable (included with the x-ray apparatus).
2- Install the collimator in the collimator mount (a).
3- Attach the goniometer to guide rods (d).
4- Make the distance from the slit diaphragm of the collimator to the target arm to be 5 cm.
5- Connect ribbon cable (c).
6- Remove the protective cap of the end-window counter, place the end-window counter in sensor seat (e).

7- Connect the counter tube cable to the socket marked GM-TUBE.
8- Set the distance between the target arm and the slit diaphragm of the sensor seat to around 6 cm by moving the sensor holder (b),
9- Mount the target holder (f) with target stage.
10- Place the NaCl crystal flat on the target substrate, and raise the target stage with crystal all the way to the stop.
11- Tighten the knurled screw.
12- Adjust the mechanical zero position of the Goniometer.

- **Procedure:**

- Start the software "X-ray Apparatus", check to make sure that the apparatus is connected correctly.
- Set the x-ray high voltage U = 35.0 kV, emission current I = 1.00 mA, measuring time per angular step Δt = 10 s and the angular step width $\Delta\beta$= 0.1°.
- Press the COUPLED key to activate 2ϑ coupling of target and sensor.
- Set the lower limit of the target angle to 2° and the upper limit to 25°.
- Check if the machine need a calibration or not.
- Start measurement and data transfer to the PC by pressing the SCAN key.
- Save the measuremens.
- Access the evaluation functions of the software "X-ray Apparatus" by clicking the right-hand mouse button and select the command "Calculate Peak Center".
- Mark the "entire width" of the peaks.
- Save your measurements and evaluations.
- Using the glancing angle ϑ and the lattice plane spacing d = 282.01 pm, calculate the wavelength l using Bragg's law of reflection.

10^{-12} m

- **Data Analysis:**

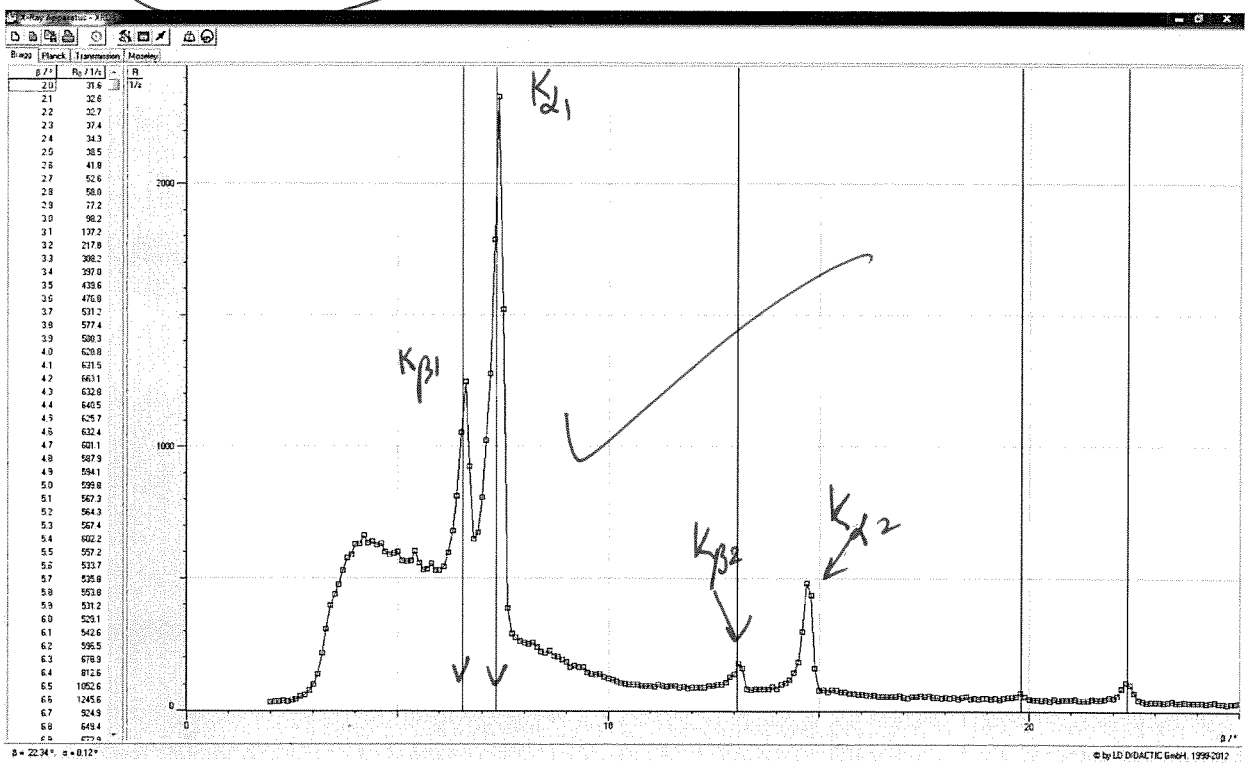


Figure 17: Diffraction spectrum of x-ray radiation for *Bragg* reflection to the third order at an NaCl monocrystal.

- **First order diffraction:**

$K\alpha 1 = 7.33^{o}$

$K\beta 1 = 6.54^{o}$

$\Delta = 7.33 - 6.54 = \mathbf{0.79^{o}}$

The theoretical value is: $\Delta = 7.24 - 6.42 = \mathbf{0.82^{o}}$

The percentage difference $= \frac{0.82-0.79}{0.82} \times 100 = \mathbf{3.66\ \%}$

- **Second order diffraction:**

  $K_{\alpha 2} = 14.72^{o}$

  $K_{\beta 2} = 13.07^{o}$

  $\Delta = 14.72 - 13.07 = \mathbf{1.65^{o}}$

  The theoretical value is: $\Delta = 14.6 - 12.94 = \mathbf{1.66^{o}}$

  The percentage difference $= \frac{1.66-1.65}{1.66} \times 100 = \mathbf{0.6\ \%}$

- **Third order diffraction:**

  $K_{\alpha 3} = 22.34^{o}$

  $K_{\beta 3} = 19.80^{o}$

  $\Delta = 22.34 - 19.80 = \mathbf{2.54^{o}}$

  The theoretical value is: $\Delta = 22.20 - 19.58 = \mathbf{2.62^{o}}$

  The percentage difference $= \frac{2.62-2.54}{2.62} \times 100 = \mathbf{3.05\ \%}$

❖ Conclusion

- All of the previous experiments are based on the same concept, which is X-ray diffraction.
- In the first experiment (Fine structure of the characteristic x-radiation of a molybdenum anode), the difference between the characteristic line in the first order diffraction is $\Delta\lambda$ = 7.9 (pm) with a percentage difference of 1.13 % from the literature value, which is 7.99 (pm).
- The fifth order diffraction run, the resulted curve does not represent any peak, despite the fact that I tried two times. The error arises because the duration of the run was very long (9 hours), so that the minimum and negligible errors occurred during any experiment accumulated and became significant. In addition, the range of angles was relatively large (from 32.5° to 40.5°).
- For the second experiment (Duane-Hunt relation and determination of Planck's constant), the Duane-Hunt relation was verified and that is by finding the Planck's constant, although there was an error of 17.6 %. The theoretical value of Planck's constant is $h = 6.63 \times 10^{-34}$(J . s) whereas my result is $h = 5.46 \times 10^{-34}$(J . s). The error happened because the curves with a time interval of 20 and 30 seconds were not as accurate as those with a time interval of 10 seconds. In addition, apparently there is a jump in some curves and this must be a misreading form the software itself.
- In the third experiment (Bragg reflection diffraction of x-rays at a monocrystal), I got good and accurate result (comparing to the literature values):

n	$\vartheta(K\alpha)$	$\vartheta(K\beta)$
1	7.33	6.54
2	14.72	13.07
3	22.34	19.8

- There are additional error sources. One of them is calibration of the X-ray machine, which I have done manually. Furthermore, in the long-duration runs, the X-ray machine's temperature rises, and this rise in the temperature affects the readings.

Muhammad Al-Lahrani

NMR

Phys403 Report Format T161 Exp #1

Phys403 Report Evaluation Criteria (Total Points =75)

(Report Contents and associated grade points)

- ☐ **Title page** — **2/75** — 2
  - **Title of the experiment**
  - **Course name and term**
  - **Name of student and ID number**
  - **Name of supervisor**
  - **Date of submission**
- X ☐ **Table of contents page**
- X ☐ **Abstract** — **4/75** — 0
  - Brief summary of the technique used and main findings.
- ✓ ☐ **Introduction** — **10/75** — 10
  - Background including, basic principle and theory, a brief review of literature.
- X ☐ Objectives — 0 → **5/75**
- ✓ ☐ **Experimental details** — **20/75** — 16
  - ✓ Description of equipment
  - ✓ Sample preparation
  - ✓ Description of methods used.
- ✓ ☐ **Results and Discussion** — **25 /75** — 22
  - ✓ States the results of the research.
  - ✓ Data analysis
  - ✓ Discussion of results
- ✓ ☐ **Conclusion** — **5/75** — 4
  - Summary of results and main findings.
- ✓ ☐ **References** — **4/75** — 4

58/75

Σ

Phys 403

Exp #1

NMR Experiment

Lab Report

Muhannad Alzahrani
201151030

Introduction

Nuclear Magnetic Resonance (NMR) happen when a nuclei absorb and then emits an electromagnetic radiation at a specific frequency called resonance frequency, depending on the strength of magnetic field and the magnetic properties of the isotope. NMR provide the physical basis for NMR spectroscopy which has an enormous applications in medical imaging, studying crystals, purity determination of chemical substances ..etc. In this experiment, we are going to use the NMR to measure the longitudinal spin-lattice relaxation time T_1 and spin-spin relaxation time T_2 for glycerin . Relaxation refers to the situation where a population of spins return to the thermal equilibrium distribution of the magnet.

Theory

Nuclear magnetic resonance fundamentally depends upon the nuclear spin (I) of an atom, which is a function of the number of protons and neutrons in its nucleus. Some atoms like $^{12}C_6$ have no intrinsic nuclear spin, though that does not mean that isotopes of these elements cannot have nuclear spin In this case, $^{13}C_6$. In this experiment, we concern ourselves with hydrogen, which has a nuclear spin I = 1/2 . Any nucleus with a nuclear spin $I \geqslant 1/2$ has a magnetic dipole moment μ oriented in the same direction as the

nuclear spin I, that can be calculated using :

$$\mu = \frac{\gamma h I}{2\pi} \qquad (1)$$

where γ is the gyromagnetic ratio of the nucleus in question (2.675×10^8 rad /(T.s) for hydrogen). Due to Zeeman effect, a magnetic field of strength B_0 will result in a splitting of states, which in the case of hydrogen will produce only two possible states for m = +1/2 or -1/2, with an energy splitting of :

$$\Delta E = \frac{\gamma h B_0}{2\pi} \qquad (2)$$

In the absence of an external magnetic field, the two states $m = \pm 1/2$ are of equal energy and are therefore equally populated. When a magnetic field is applied, the energies are changed and the states become unequally populated, which introduces a magnetization M_0 in the direction of the magnetic field. If the system in equilibrium is then excited by an electromagnetic pulse with an energy ΔE, the spin will be excited to the next higher energy state. This process will change the total magnetization of the system, which will eventually return the equilibrium state through the process of relaxation.

In this experiment, we will focus on spin-lattice (T_1) and spin-spin (T_2) relaxation times. Spin-lattice relaxation time (so called because energy gained from the electromagnetic pulse must be dissipated through the lattice of the matrix) is defined in terms of the relaxation of the

z-component of magnetization M_z after it has been inverted by a 180° " π -pulse", which is characterized by the Equation :

$$M_z(t) = M_0\left[1 - \exp\left(-\frac{t}{T_1}\right)\right] \qquad (3)$$

where T_1 is the time constant of the exponential decay, and it can interpreted the time it takes for the net magnetization to decay to 1/e ($\approx$ 36.8%) of its original value. Due to the large external magnetic field, the measurement of magnetization will be occluded only to the z-direction which is the assumed direction of B_0. To avoid this, we subject the inverted magnetization to a $\pi/2$-pulse a time t after the inverting π -pulse, shifting the magnetization vector into xy-plane, which can be measured without being affected much by the large magnetic field. Performing this operation, known as an inversion-recovery sequence, for various times t can allow for the time constant T_1 to be determined using Equation (3).

On the other hand, spin-spin relaxation is the process by which spins rotated into the xy-plane by a $\pi/2$-pulse decay back to the z-axis. The process is known as spin-spin relaxation because the nuclei relax to their equilibrium magnetization in the z-direction through interactions with each other.

The random of atomic nuclei, in addition the intrinsic spin of each nucleus, generates localized oscillating magnetic fields that can occasionally stimulate spin relaxation in nearby nuclei by resonating with the Larmor precession frequency. This phenomenon is characterized by:

$$M_{xy}(t) = M_0 \exp\left(-\frac{t}{T_2}\right) \qquad (4)$$

where T_2 is the time constant of the exponential decay, equal to the time it takes for the magnetization in the xy-plane to decay to 1/e ($\approx$ 36.8%) of its equilibrium value. Inhomogeneities of the external magnetic field cause the sample spins to decohere in the xy-plane before total relaxation to the z-axis, which will make a direct measurement of the decay of the magnetization is nontrivial or infeasible. Overcoming this obstacle can be done via The Hahn spin-echo sequence through inverting π - pulse some time τ after the spins are rotated into the xy-plane.

The π -pulse inverts the spins, but does not alter their momenta, so the decoherence process reverses itself and after another time period τ a coherent signal – the echo – can be measured. By varying the time τ and measuring the signals at coherence (2τ), a fit for Equation 4 can be achieved and T_2 can be calculated.

Experimental

1)Instruments:

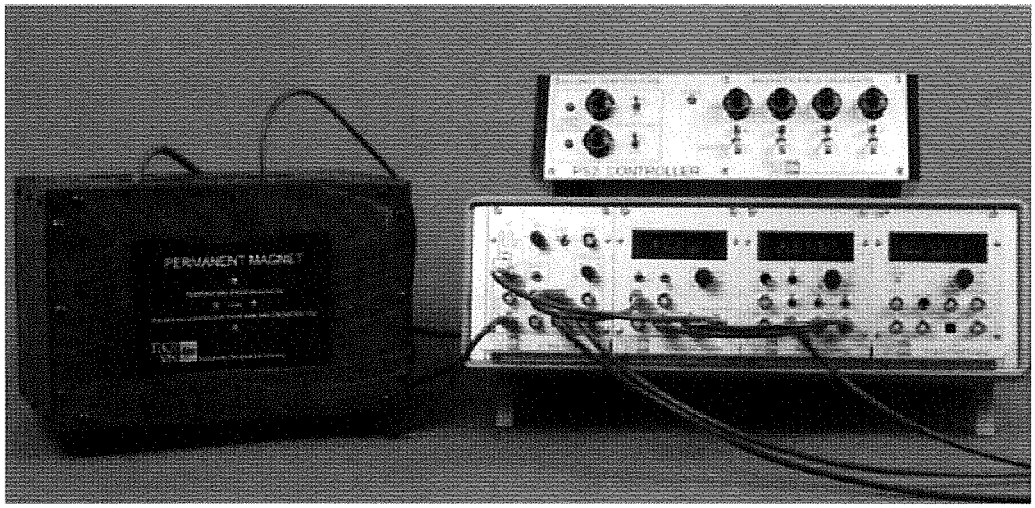


Figure 4: The PS2-A Spectrometer: Magnet, Mainframe and PS2 Controller

As in the figure, the setup consists of the magnet, PS2 controller which is used to control the magnetic field gradient and mainframe which contains the receiver, synthesizer, pulse programmer and lock-in/field sweep. In addition, an oscilloscope is used to to measure the voltage.

2) Procedure:

The procedure consists of several steps:

2-1) Setting the Frequency for the Procession of a Proton:

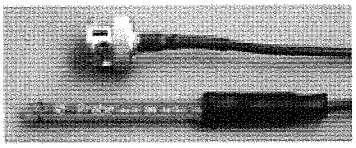
We need to setup the parameters to the default options

Table 1: Default PSA-2 settings

SYNTHESIZER	PULSE PROGRAMMER
F (Frequency): 21.65000 MHz	A (A (first) pulse length): 0.02 μs
P (Refer Phase): 180°	B (B (second) pulse length): 0.02 μs
A (CW Pwr): - 10 dBm	*t* (time between pulses): 0.0001 s
S (Sweep): 0 kHz/V	N (number of B pulses): 0
	P (repeat pulse sequence period) 0.2 ms

2-3) Tuning the magnet:

The instrument must be tuned and shimed to the Larmor precession frequency of the proton in the ambient magnetic field using the RF probe



1- Place the RF pickup in the magnet sample holder. Attach the BNC connector to Channel 1 of the oscilloscope.

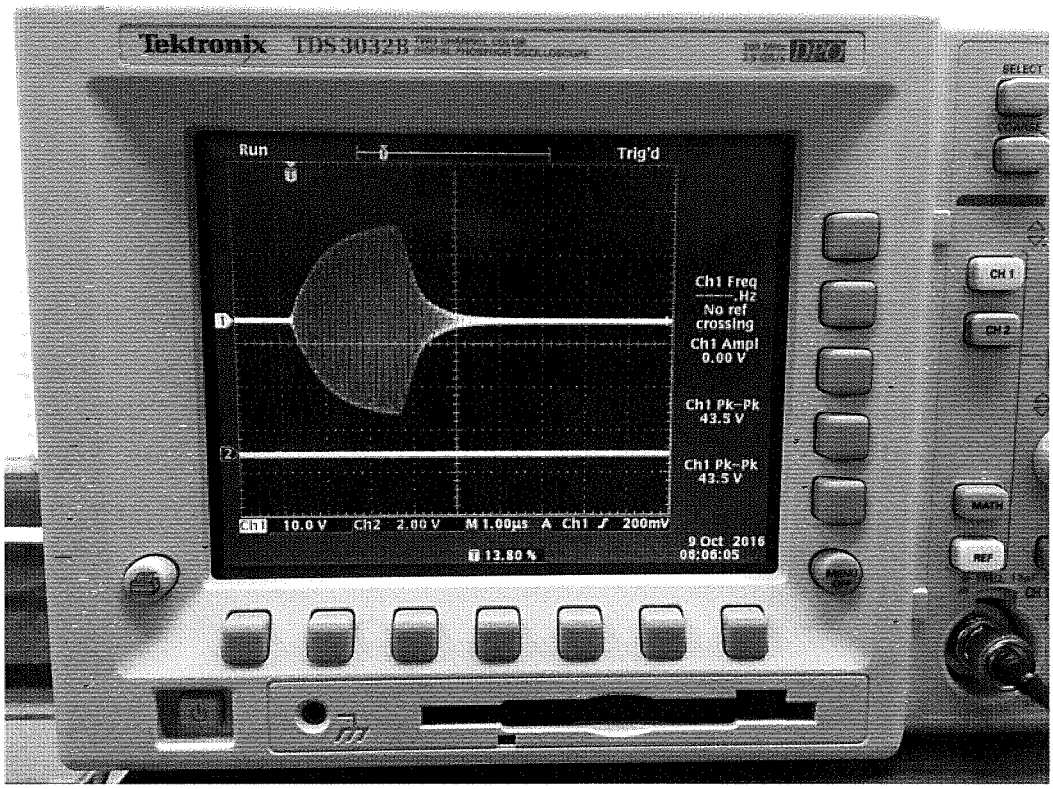
2- Set the A pulse to 2.5 μs.

3- Set the Period to 1.00ms

4- Make sure the following toggle switch positions are correct on the Pulse Programmer: Sync: A A Pulse: On B Pulse: Off .

5- Adjust the Oscilloscope settings: a. Push the "TRIG MENU" button. On the right part of the screen you' ll see options. Set these to the following; Type- edge; Source-ext; Slope - Rising; Mode - Normal; Coupling - DC. With the Trigger level dial, adjust it to 0.1 V (see display) b. Push the "MEASURE" button. Makes sure it is set to Channel 1 and the measurement method (second option from top on the display) is set to Pk-Pk. This will give you the size in volts of your signal. c. On the Horizontal menu use the SEC/DIV and adjust to 1.00 μs/DIV. You can adjust the positioning of the signal on the screen by using the Horizontal and Vertical knobs. A DIV is simply the divisions (grid) on the display. d. Set Channel 1 to 5.00 V/DIV.

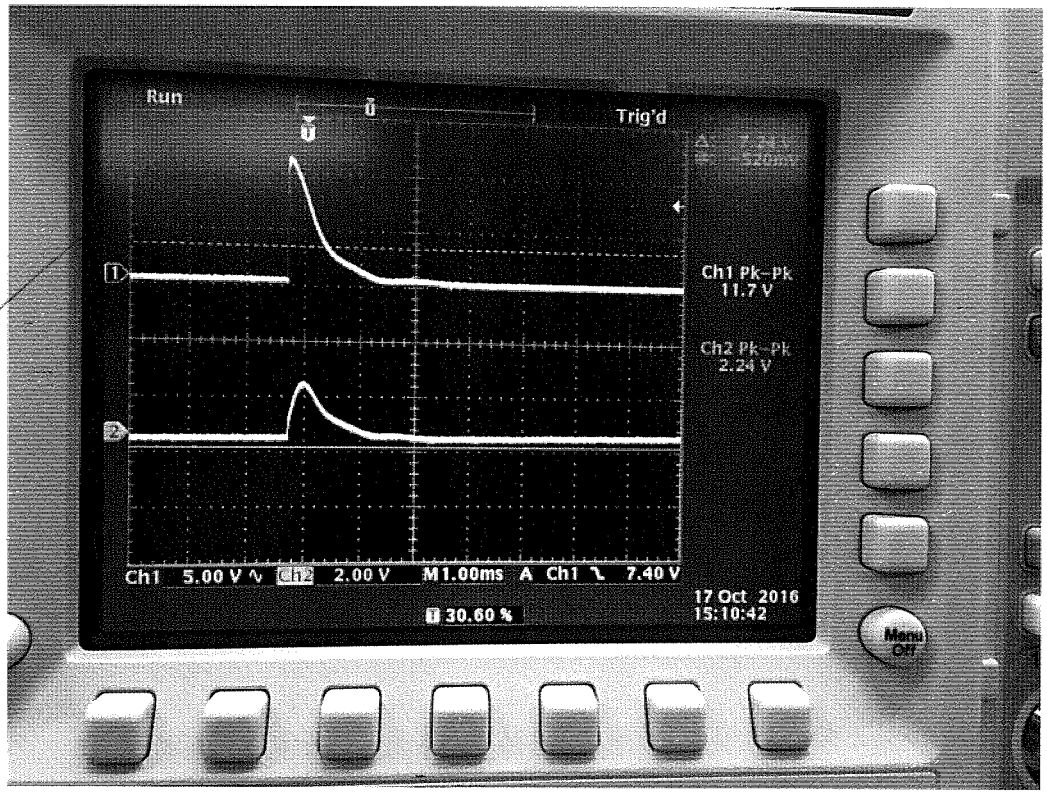
If the RF Sample Probe is properly tuned, one should observe an RF burst of about 60 volts peak-to-peak lasting about 3 μseconds depending on the instrumentation, in our case the maximum peak-to-peak voltage obtained was 43.5 V.



2-4) Preparing T_1 measurements

The RF burst that tips the magnetization from its thermal equilibrium orientation along the z-axis (the direction of the DC magnetic field) to create some transient component along the x-y plane, which happen in a scale of microseconds. But this x-y magnetization precesses in the x-y plane for times of the order of milliseconds. Thus, the sweep times on the oscilloscope need to be adjusted accordingly.

Next, we switch to channel 2 and use the obtained signal to fine-tune Larmour frequency, this is done by adjusting frequency continuously until we have stable non-oscillating signal, what we got at this stage is showed in the figures below.



During the experiment we noticed several things: First, Frequency must be adjusted to get a stable optimum signal. Second, magnetic field gradient X, Y, Z and Z^2 must be adjusted and balanced for the same purpose as in the first part. Third, the effect of magnetic field gradient changing was not the same for all directions, while X and Z^2 change the signal significantly, the effect of changing Y and Z was negligeable. Finally, getting a stable and clean signal involves changing all these different parameters

simultaneously, which was the hardest part.

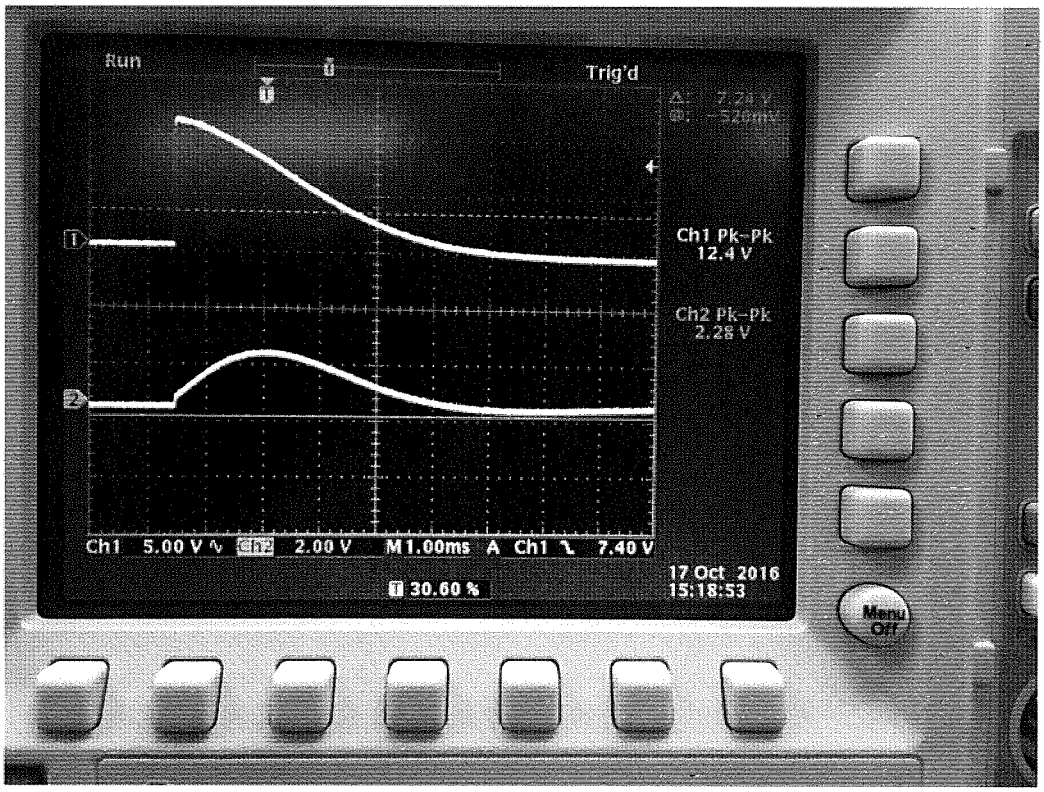
2-5)Determining the 90 and 180 degree pulse length for glycerin

Now we must determine the length of time needed for a 90° pulse and a 180° pulse so that you can find the samples' relaxation times with the correct sequence. The experimental criterion for obtaining a 180° pulse, that is an RF burst that rotates the thermal equilibrium magnetization from the + z to – z axis, is a pulse approximately twice as long as a 90° pulse, yet one that leaves no FID signal after it, and the pulse length that achieves the biggest signal is the 90°.

For the glycerin we got the max signal at A_length = 2.6 V , which correspond to the 90° ,and the min and A_length = 9.5 V, which correspond to the 180° pulse.

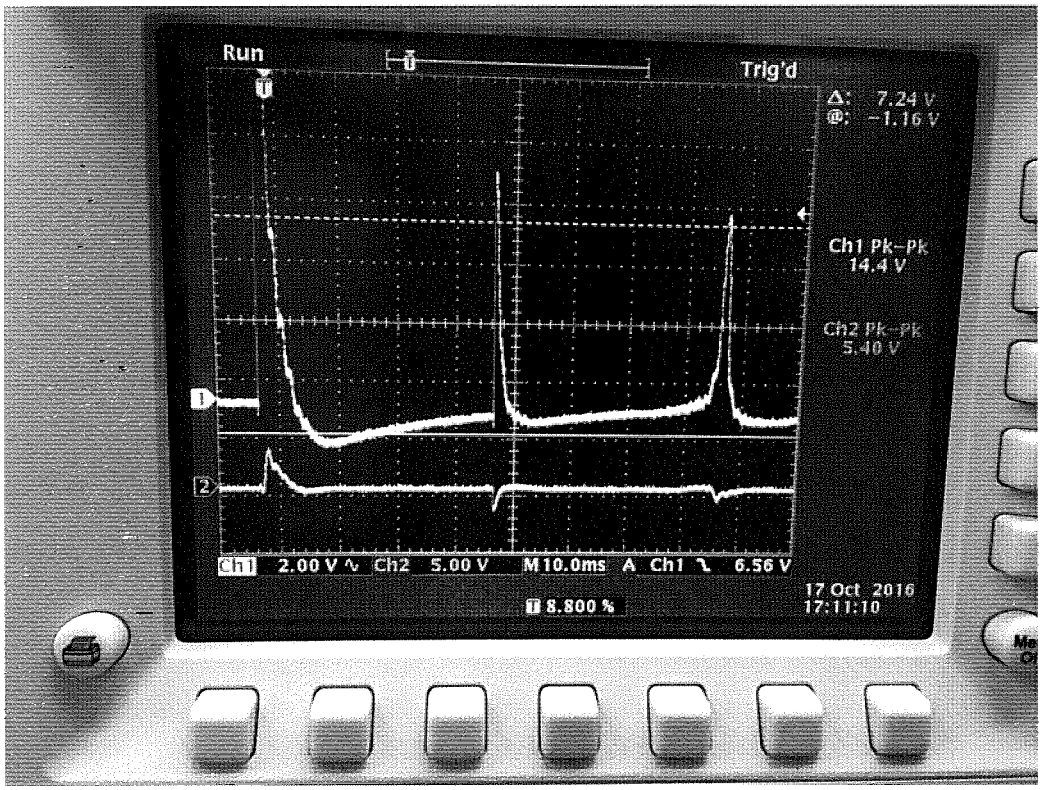
2-6)Determining T_1 for glycerin

Now that you have found the 90 and 180 pulse lengths for the sample, T_1 can be determined by using the pulse sequence discussed in the intro of 180 pulse --> tau --> 90 pulse and measuring the signal intensity change with respect to changes in tau (t), then by varying tau within the range and using Equation 3 and best-fit line (Regression line) we can obtain the value of T_1, which will be discussed later in the data analysis section. Below is the signal form for the first measurement of the magnetization.



2-7) Determining T_2 for glycerin

The spin-spin relaxation time (T2) describes the decay rate of the magnetization within the x-y plane back to equilibrium after a 90 degree pulse. T2 can be determined by utilizing a spin echo experiment which involves the following pulse sequence, 90° pulse --> tau --> 180° pulse --> tau -->echo signal. Finding T_2 from tau measurement will be discussed in the data analysis section. Below is the signal shape for the first measurement of the magnetization.



In this specific experiment to measure T_2 we had a difficulty in taking enough data points, due to the fact that the signal become increasingly unstable and highly oscillatory while increasing the value of tau. Therefore, we took close values for tau.

Data Analysis

A) T_1 Measurement

To determine T_1, we are going to use the least-squares method, also known as linear regression. Taking the natural Logarithm of equation 3 and re-arranging will give:

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

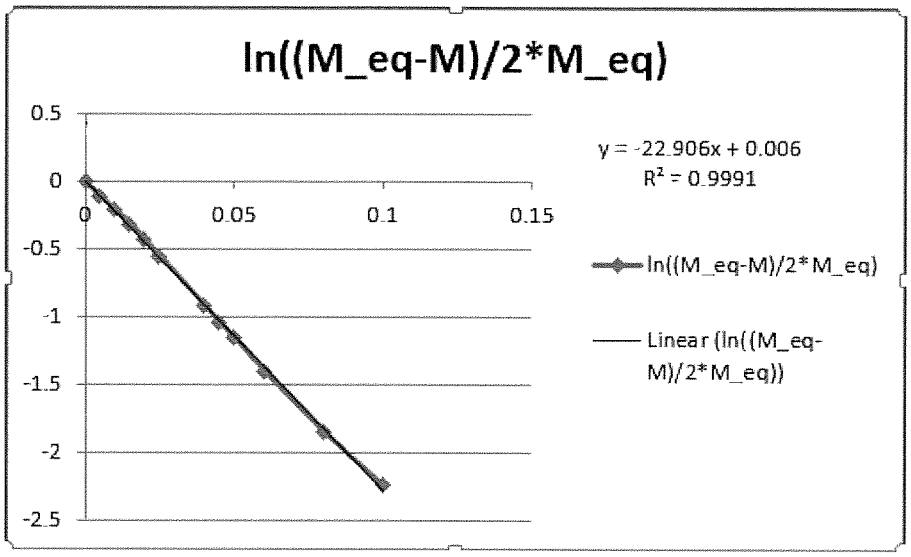
Therefore, fitting the ln in the left hand-side vs. Tau will give us T_1.

The obtained data set for the magnetization given tau are listed below.

How did you set M_eq ??

tau	M(t) two	M_eq	ln((M_eq-M)/2*M_eq)
0	-12.6	12.7	-0.003944778
0.005	-9.95	12.7	-0.114589322
0.01	-7.8	12.7	-0.214324288
0.015	-5.8	12.7	-0.316978442
0.02	-3.8	12.7	-0.431388793
0.025	-1.95	12.7	-0.550308839
0.04	2.55	12.7	-0.917275469
0.045	3.73	12.7	-1.040863498
0.05	4.7	12.7	-1.155307632
0.06	6.44	12.7	-1.400568989
0.08	8.7	12.7	-1.848454813
0.1	10	12.7	-2.241497401

Plotting the last vs. First columns to obtain the least-squares approximation gives:



Using the aforementioned equation, the slope is $-1/T_1$, which will produce the value $T_1 = 0.04366$ s for the glycerin.

43.66 ms

B) T_2 measurement

In the same manner used to determine T_2 we will find T_2.

Linearizing equation 4:

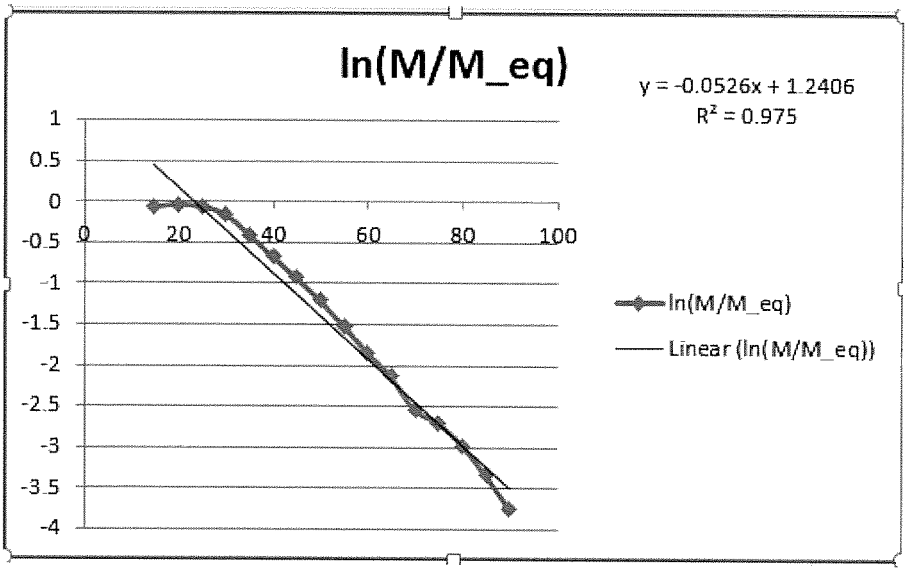
$$\ln\left[\frac{M_{xy}(2\tau)}{M_{eq}}\right] = -\frac{2\tau}{T_2}$$

??

Thus, plotting the left-hand side vs. Tau will give T_2 just as we did with T_1.

The obtained data set is below.

tau	M(t)	M_eq	ln(M/M_eq)
15	12	12.7	-0.0566953
20	12.3	12.7	-0.0320027
25	12	12.7	-0.0566953
30	10.9	12.7	-0.1528392
35	8.5	12.7	-0.4015358
40	6.5	12.7	-0.6697998
45	5	12.7	-0.9321641
50	3.8	12.7	-1.2066009
55	2.8	12.7	-1.5119826
60	2	12.7	-1.8484548
65	1.5	12.7	-2.1361369
70	1	12.7	-2.541602
75	0.85	12.7	-2.7041209
80	0.65	12.7	-2.9723849
85	0.45	12.7	-3.3401097
90	0.3	12.7	-3.7455748



Therefore, using the linearized eq(4) we get $T_2 = 19.01$ s

For glycine you got $T_1 = 43.66$ ms & $T_2 = 19.01$ ms

" " references $T_1 = 40$ ms & $T_2 = 37.1$ ms

$.05 = \frac{5}{100} = \frac{1}{20} \Rightarrow 20$

Explain

Discussion

A few points we are going to mention / discuss about the experiment and it's result.

1- We noticed a large deviation in the relation between T_1 and T_2 for the glycerin , which can be interpreted by the effect of the impurity which can not be ignored for the glycerin, unlike the light or heave oil we we have an excellent agrement.

?? you did not do this experiment!!

2- Why T_1 is larger than T_2 ? (In general)

During relaxation, electromagnetic energy is retransmitted: this RF emission is called the NMR signal. Relaxation combines 2 different mechanisms: Either longitudinal relaxation which corresponds to longitudinal magnetization recovery, or transverse relaxation which corresponds to transverse magnetization decay. Longitudinal relaxation is due to energy exchange between the spins and surrounding lattice (spin-lattice relaxation), re-establishing thermal equilibrium. As spins go from a high energy state back to a low energy state, RF energy is released back into the surrounding lattice.

The recovery of longitudinal magnetization follows an exponential curve. The recovery rate is characterized by the tissue-specific time constant T_1. After time T_1, longitudinal magnetization has returned to 63 % of its final value. With a 1.5 T field strength, T_1 values are about 200 to 3000 ms. T_1 values are longer at higher field strengths. Transverse relaxation results

from spins getting out of phase. As spins move together, their magnetic fields interact (spin-spin interaction), slightly modifying their precession rate. These interactions are temporary and random. Thus, spin-spin relaxation causes a cumulative loss in phase resulting in transverse magnetization decay.

Transverse magnetization decay is described by an exponential curve, characterized by the time constant T_2. After time T_2, transverse magnetization has lost 63 % of its original value.

T_2 is tissue-specific and is always shorter than T1. Transverse relaxation is faster than longitudinal relaxation.T_2 values are unrelated to field strength.

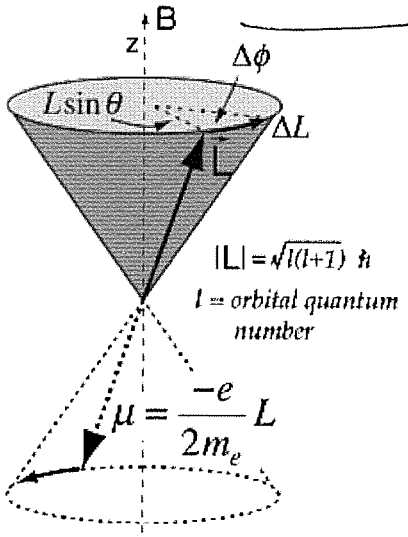
3- Why does the Larmor precessional frequency change with magnetic field? We will answer this question be referring to the basic physics of the problem.

When a magnetic moment m is placed in a magnetic field B, it experiences a torque which can be expressed in the form of a vector product:

$$\tau = \mu \times B$$

For a static magnetic moment or a classical current loop, this torque tends to line up the magnetic moment with the magnetic field B, so this represents its lowest energy configuration. But if the magnetic moment arises from the motion of an electron in orbit around a nucleus, the magnetic moment is proportional to the angular momentum of the electron.

The torque exerted then produces a change in angular momentum which is perpendicular to that angular momentum, causing the magnetic moment to precess around the direction of the magnetic field rather than settle down in the direction of the magnetic field. This is called Larmor precession.



When a torque is exerted perpendicular to the angular momentum L, it produces a change in angular momentum DL which is perpendicular to L, causing it to precess about the z axis. Labeling the precession angle as f, we can describe the effect of the torque as follows:

$$\tau = \frac{\Delta L}{\Delta t} = \frac{L\sin\theta\Delta\phi}{\Delta t} = \left|\mu B\sin\theta\right| = \frac{e}{2m_e}LB\sin\theta$$

Thus, the precession angular velocity (Larmor frequency) is:

$$\omega_{Larmor} = \frac{d\phi}{dt} = \frac{e}{2m_e}B$$

Which expresses the explicit dependence on B

References

1- Wagner, E.P. Understanding Precessional Frequency, Spin-Lattice and Spin-Spin Interactions in Pulsed Nuclear Magnetic Resonance Spectroscopy. 2014.

2- Pulsed Nuclear Magnetic Resonance: Spin Echoes .MIT Department of Physics , 2014.

3- Measuring Material Properties With Pulsed NMR.Pranjal Vachaspati, Jenelle Feather, 2012.

4- Hyper-physics. Larmor Precession

5- Pulse NMR Spectroscopy.Jonathan Melville, 2014.

Maleki

OPTICAL PUMPING

Exp #3

Phys403 Report Format T161

Phys403 Report Evaluation Criteria (Total Points =75)

(Report Contents and associated grade points)

- ☐ **Title page** — 2/75
  - **Title of the experiment**
  - **Course name and term**
  - **Name of student and ID number**
  - **Name of supervisor**
  - **Date of submission**
- ☐ **Table of contents page**
- ☐ **Abstract** — 4/75
  - Brief summary of the technique used and main findings.
- ☐ **Introduction** — 10/75
  - Background including, basic principle and theory, a brief review of literature.
- ☐ Objectives — 5/75
- ☐ **Experimental details** — 20/75
  - Description of equipment
  - Sample preparation
  - Description of methods used.
- ☐ **Results and Discussion** — 25 /75
  - States the results of the research.
  - Data analysis
  - Discussion of results
- ☐ **Conclusion** — 5/75
  - Summary of results and main findings.
- ☐ **References** — 4/75

2 3 8 3 18 20 3 2

59/75

Exp #3

King Fahd University of Petroleum and Minerals

College of Sciences

Department of Physics

Phys 403 – Senior Physics Laboratory

Term (161)

Report Title: **Optical Pumping**

Supervised by

Dr. Akhtar Naqvi

Name: **Hesham Almaleki**

ID: **201175730**

14 December 2016

❖ Abstract

This report is discussing the Zeeman effect and Hyperfine structure of rubidium atom by performing tests using optical pumping. A Rubidium high-frequency lamp is used as the pumping light source to excite Rubidium atoms in a sample cell. The light is filtered and polarizers are used to produce circular polarization, which will populate the ground state Rb Zeeman hyperfine levels away from thermal equilibrium.

❖ Introduction

- **Objectives**

The main objective of this experiment is to measure the Zeeman splitting of the hyperfine structure components of the ground state of rubidium in a known weak magnetic field.

- **Background**

a) Quantum Theory of Hydrogenic Atoms

- In Optical Pumping experiment the light (basically resonant radiation) is used to change the population of a set of energy levels of a system 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. The atomic ground states and all excited states experience splitting in the energy levels. They will be split into a number of sub-states which are designated as hyperfine states. This occur because of the existence of a nuclear spin of the atom. The splitting in the energy level arises from the interaction with the external magnetic field. The orbital angular momentum of the electron (L) produces a dipole moment, This dipole moment interacts with the spin (S) of the electron. These vectors add to give a total angular momentum of the electron,

$$J = L + S$$

Each vector has an associated quantum number; S,L and J. J can take on different values even for the same S and L because L and S can point in different directions. The J values split the gross structure into corresponding energy levels.

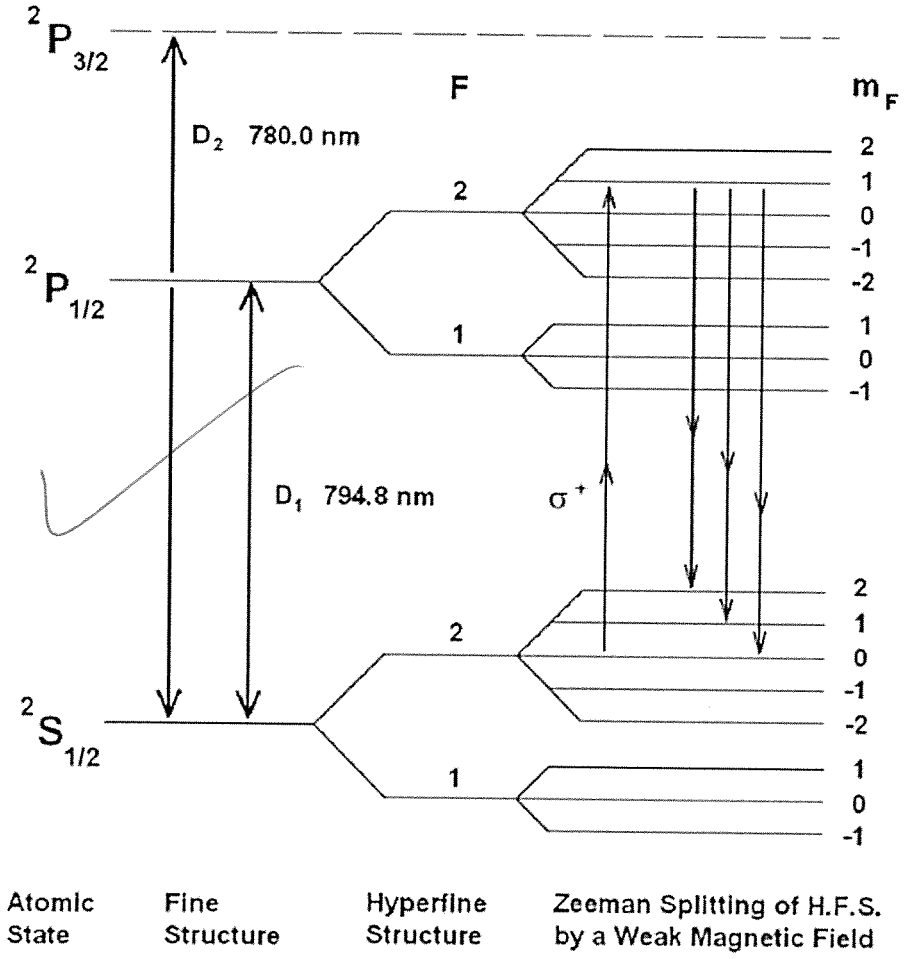


Fig 1: Energy level splitting in the rubidium atom (Rb).

b) Zeeman Effect

- The Zeeman Effect: is the splitting of electronic energy levels in a magnetic (B) field. Note that the spacings of The Zeeman levels are equal. This is not the case for high magnetic field. A vapour of free rubidium atoms (Rb) when placed in a weak magnetic field will create the Zeeman splitting of the hyperfine structure. The splitting is given by:

$$\Delta E = g_F \mu_0 B M_F$$

Where:

$$g_F = g_J \frac{F(F+1) + J(J+1) - I(I+1)}{2F(F+1)}$$

and:

$$g_J = 1 + \frac{J(J+1) + S(S+1) - L(L+1)}{2J(J+1)}$$

c) Absorption

The outgoing flux of photons can be related to the ingoing flux as follows:

$$I = I_0 e^{-\sigma_0 \rho l}$$

Where:

σ_0 is the maximum absorption cross section measured at the centre of atomic resonance.

ρ *is* the density of Rb gas

l is the path length (distance travelled through gas).

The cross section represents the area over which the particles interact with the atom. In the case of light, the cross section may be Significantly different to the geometrical cross section because of the process of resonance.

d) Optical Pumping

Normally light is polarised in random orientations. Light can be linearly polarised (π-polarised), and it can also be circularly polarised (σ-polarised). This means that the electric field rotates about the optical axis. The interesting thing about circularly polarised light is that it has angular momentum.

The selection rules are:

$$\Delta M_F = \pm 1$$
$$\Delta F = 0$$

This will produce transition in the Zeeman sub-levels, which will redistribute the electrons from the state they are in when they optically pumped.

❖ Experimental details

- **Apparatus**

The experimental setup is as follows:

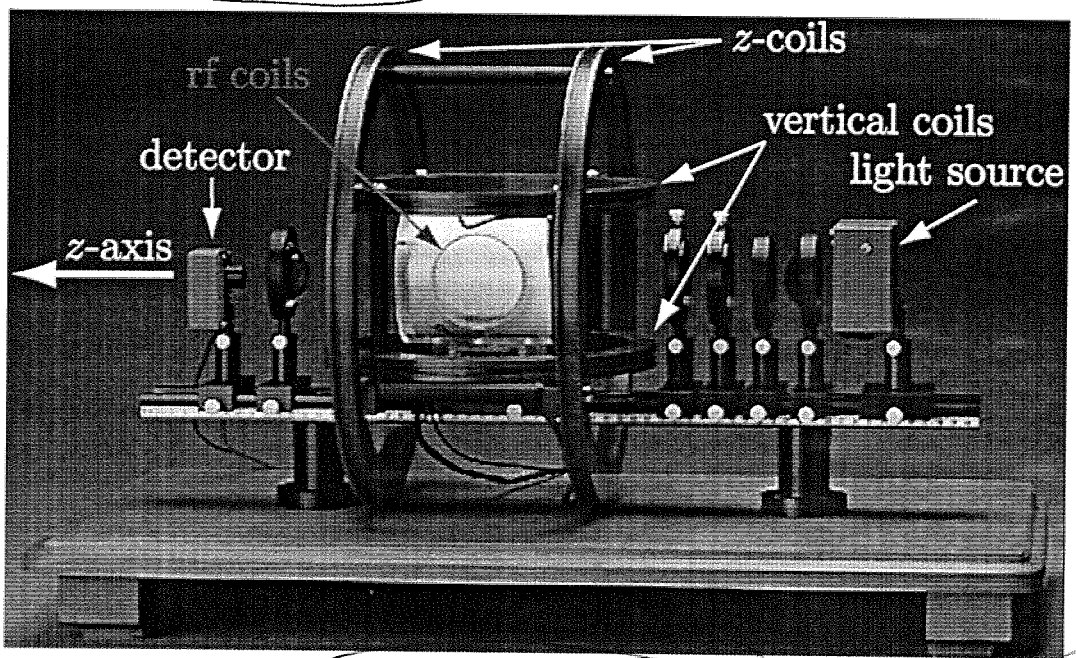


Fig 2: Optical pumping apparatus.

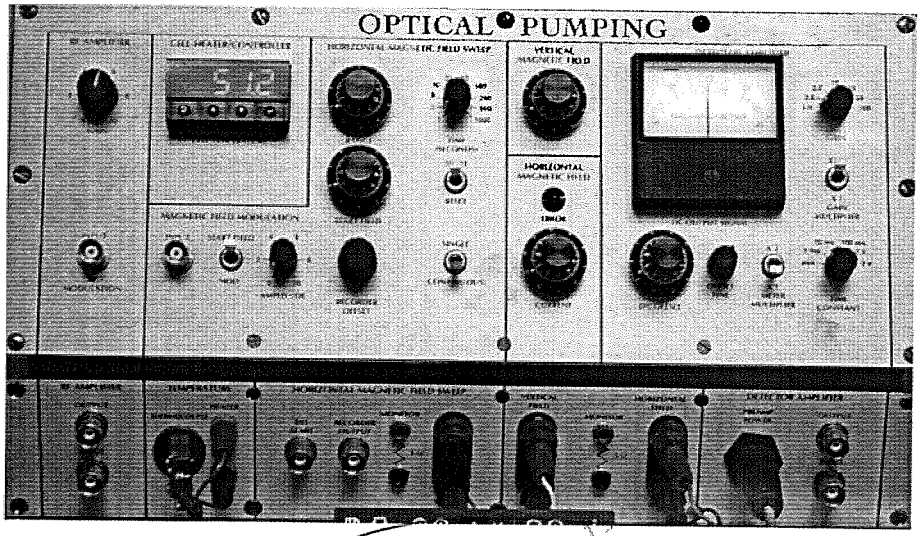


Fig 3: Control unit.

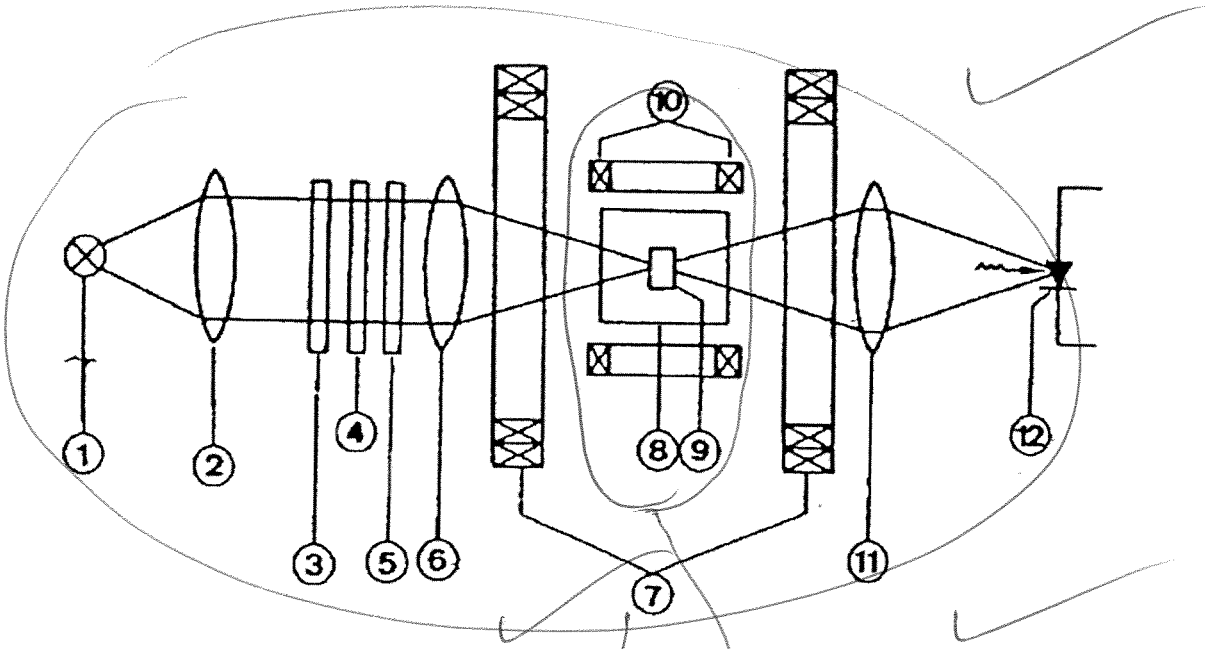


Fig 4: Schematic drawing of the Experimental Setup.

1- A high-frequency rubidium lamp.
2- A lens to focus the lamp light.
3- An interference filter.
4- A linear-polarization filter.
5- A λ/4 plate.
6- A lens with a short focal length.
7- Helmholtz coils.
8- The absorption chamber.
9- The absorption cell.
10- HF coils.
11- A lens with a short focal length
12- A silicon photodetector

- **Description of Equipment**
  - The high-frequency rubidium lamp plays the role of the light source.
  - This light is then focused using the lens.
  - The interference filter, the linear-polarization filter, and the $\lambda/4$ plate are used to separate the σ^+ circularly-polarized component of the D_1 line from the emission spectrum of the rubidium lamp.
  - The short-focal length lens focuses the generated light after the filtration.
  - The absorption chamber and the absorption cell, which contains the rubidium sample, are positioned between the Helmholtz coils. This is done in order to generate a magnetic field that is needed for the Zeeman separation to take place.
  - The transmitted light is focused again by a short-focal length lens.
  - The transmitted light will be detected by the silicon photodetector.
  - The photodetector shall be connected to the Oscilloscope.
  - The HF coils must be oriented perpendicularly with respect to the Helmholtz coil field.

- **Sample preparation**

The alkali-metal atoms are often used for optical pumping because they have a single valence electron which is very similar to a hydrogen atom. In this experiment we are using rubidium (Rb).

The electron configuration of the rubidium atom is as follows:

$$1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 5s$$

As we can see, the first 36 electrons are in closed sub-shells which means that they will not have a real effect in our situation (because their total angular momentum is zero). The remaining 5 electrons are free (valence electrons) just like in Hydrogen atom.

- **Experiment Procedure**

1- Turn on the power supply for the laser.
2- Make sure that the height of all the components is centred at the height of the centre of the cell.
3- Wait until the cell heats up to 50 degrees. This takes almost 25 minutes.
4- The heating process can be faster if the apparatus is covered by a cloth (it will prevent the effect of room temperature on the apparatus).
5- Make sure that the laser beam passes through the cell using an IR card.
6- Use IR card again to verify that the laser beam hits the photodiode.
7- Connect the photodiode to the Oscilloscope.
8- Set the gain of the detector to be 10 MΩ
9- Set the detector amplifier gain to be 1.
10- Adjust the gains on the detector so that we can pick up a very small variation in intensity.
11- Observe the absorption dip when the laser wavelength is in resonance with the atomic transition.
12- Record the values of voltage corresponding to the cell temperature which will be increases gradually from room temperature (27 °C) up to (127 °C).

❖ Results and Discussion

Temperature (Celsius)	Temperature (Kelvin)	Output Voltage (V)
27	300	2.0687
37	310	1.9098
47	320	1.6056
57	330	1.1907
67	340	0.7795
77	350	0.5099
87	360	0.3697
97	370	0.3046
107	380	0.2747
117	390	0.2541
127	400	0.2487

Table 1: Density of Rb atoms as a function of temperature.

Temperature (Kelvin)	Density (atoms/m^3)
300	1.1E+16
310	2.9E+16
320	7.5E+16
330	1.8E+17
340	4.3E+17
350	8.3E+17
360	1.5E+18
370	3.7E+18
380	6.3E+18
390	1.2E+19
400	2.4E+19

Table 2: Density as a function of Temperature.

From Table (1) and Table (2) we can plot V vs the atom density.

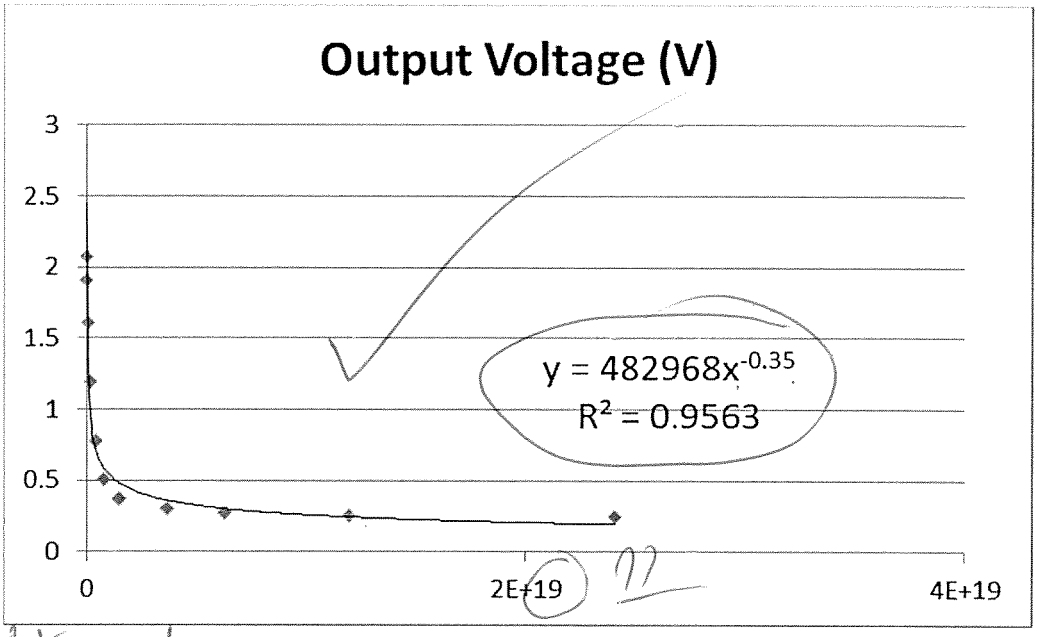


Fig 5: Detector Voltage vs Density.

From the curve,

$0.025\sigma x10^{-16} = 0.035$

thus,

$\sigma = 1.5x10^{-16}$ (m^2)

❖ Conclusion

What we did in this experiment is understanding the Zeeman Effect and Hyperfine structure of rubidium atom by performing tests using optical pumping.
Furthermore, I calculated the value of the absorption cross-section.
The value of the absorption cross-section is:

$$\sigma = 1.5x10^{-16}\ (m^2)$$

$$Percentage\ difference = \frac{1.6x10^{-16} - 1.5x10^{-16}}{1.6x10^{-16}} x100$$

$$Percentage\ difference = 6.25\ \%$$

This experiment was not complete because a critical part of the experiment (Zero Field Resonance) could not be found experimentally. Most probably because the apparatus used in the lab experiences lots of error and I think that it needs maintenance.

❖ References List

1- D. J. Griffiths, Introduction to Quantum Mechanics.
2- Techspin Manual: Optical pumping expeirment.

Al- Jama

Diode Laser

Phys403 Report Format T161

Exp #1

Phys403 Report Evaluation Criteria (Total Points =75)

(Report Contents and associated grade points)

☐ **Title page**	2	**2/75**
• **Title of the experiment**		
• **Course name and term**		
• **Name of student and ID number**		
• **Name of supervisor**		
• **Date of submission**		
☐ **Table of contents page**		
☐ **Abstract**		**4/75**
• Brief summary of the technique used and main findings.		
☐ **Introduction**	8	**10/75**
• Background including, basic principle and theory, a brief review of literature.		
☐ Objectives	4	**5/75**
☐ **Experimental details**	18	**20/75**
• Description of equipment		
• Sample preparation		
• Description of methods used.		
☐ **Results and Discussion**	20	**25 /75**
• States the results of the research.		
• Data analysis		
• Discussion of results		
☐ **Conclusion**	2	**5/75**
• Summary of results and main findings.		
☐ **References**	0	**4/75**

54/75

Exp #1

Diode Laser Experiment Report

Name : Ahmad Al-Jama

ID : 201257400

Term : 161

I. Objective

- To measure the absorption spectrum of Rubidium.

II. Theory

a. Atomic Structure of Rubidium

There are two naturally occurring isotopes : ^{85}Ru with 72% abundance and nuclear spin quantum number I = 5/2, and ^{87}Ru with 28% abundance and nuclear spin quantum number I = 3/2. The Rubidium ground-state consists of closed shells in addition to one 5s electrons, which results in a spectrum similar to Hydrogen. For the first excited state, the 5s electron moves up to 5p.

The different energy levels are represented by $^{2S+1}L_J$

where :

S : The spin quantum number.

L : The spectroscopic notation of the total orbital angular momentum.

J = L+S : The total angular momentum.

For the ground state of Rubidium (S = ½, L = 0), J = ½ . Therefore it can be represented as $^2S_{1/2}$. For the first excited state (S = ½, L = 1), J = 3/2 or 1/2. Thus, there are two excited states $^2P_{1/2}$ and $^2P_{3/2}$. Spin-orbit coupling splits these two (otherwise degenerate) states.

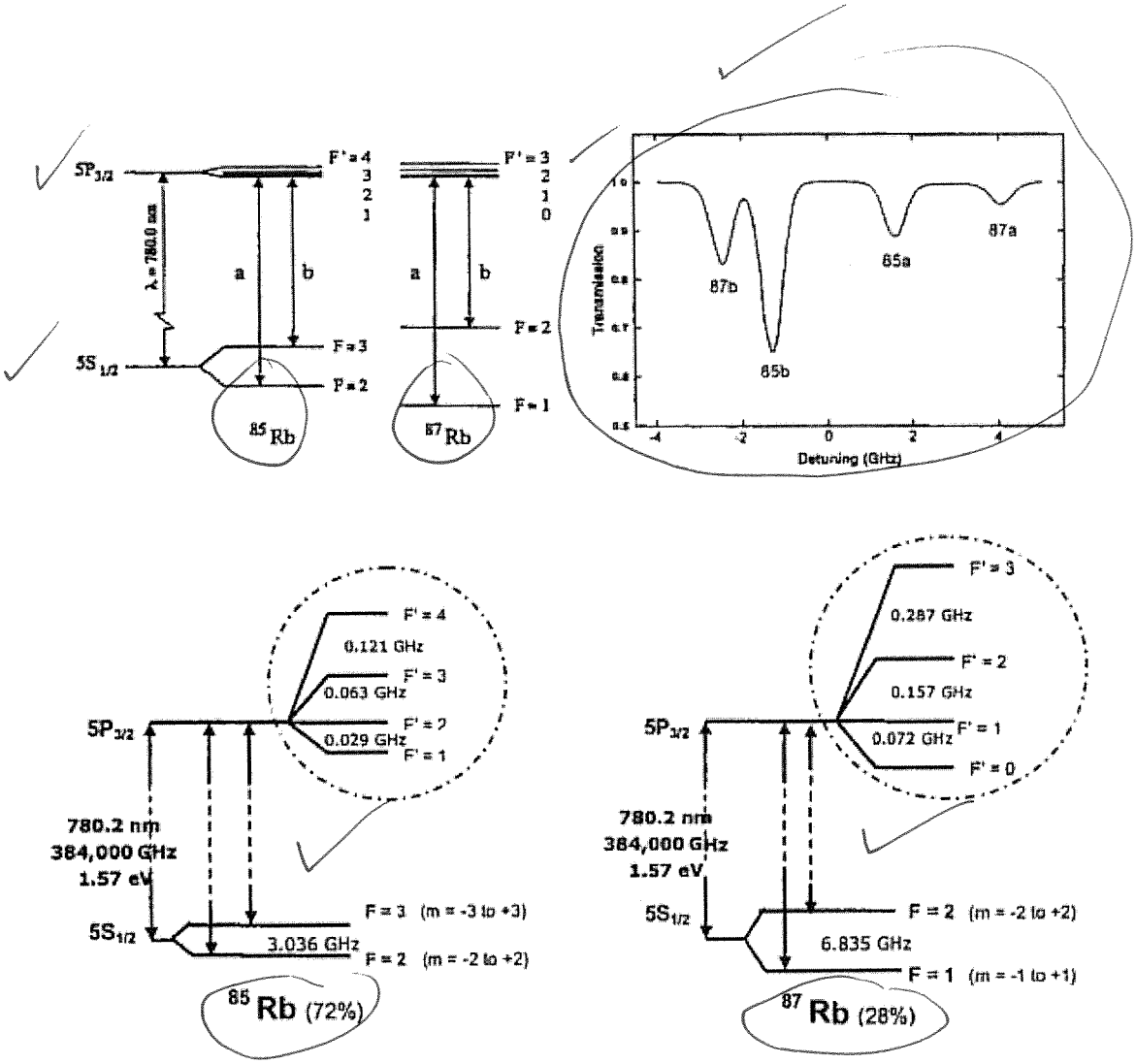
The dominant term in the nuclear spin-electron interaction gives rise to hyperfine splitting. The resulting energy splitting is :

$$\Delta E = \frac{C}{2}\left[F(F+1) - I(I+1) - J(J+1)\right]$$

Where :

F = I + J : The total angular momentum quantum number.

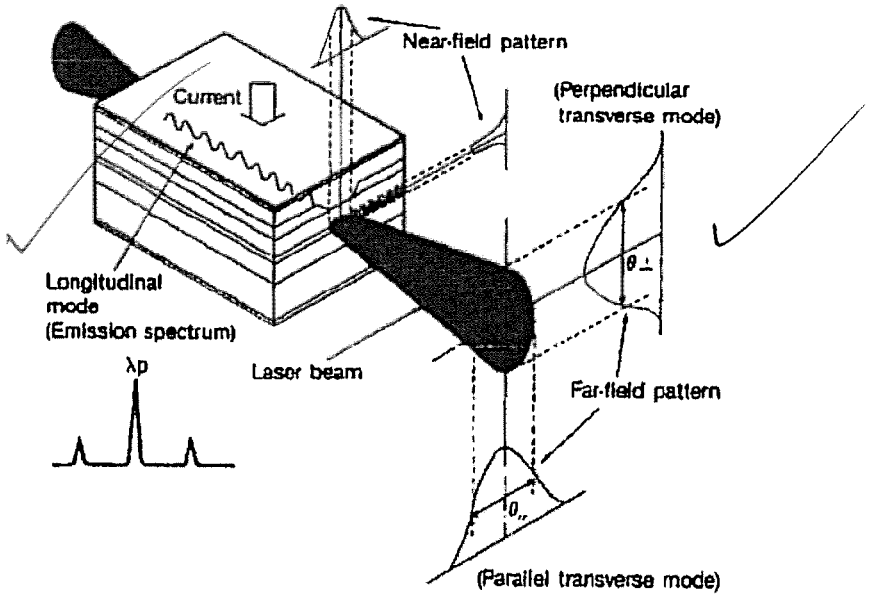
C : The hyperfine structure constant.

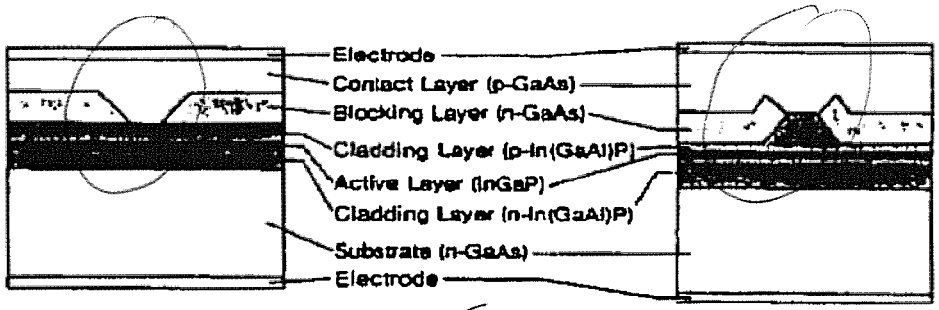


b. Diode Laser

1- Structure and Mechanism

The main part of a laser diode is a semiconductor chip. Figure 1 shows the detailed structure of the LD chip. Current runs vertically downward through the cell exciting the atoms and producing electron-hole pairs which are injected into the active layer of the n-p junction to emit light. By total internal refraction (Since the index of refraction of the active layer is larger than that of its surroundings. See Fig 2), the light is confined to a channel of dimensions (height, width, length) = (~ 2 microns, ~ 10 microns, ~ 400 microns). In order to make most of the light come out from the front facet, the front and back facets are designed to have different reflectivities. Because of the mechanism used to emit the light, its wavelength is approximately equal to that of the material's band gap.





A single longitudinal mode can be produced by careful construction i.e. the waves emitted by the laser can be made to have a fixed number of nodes along the cavity direction and no nodes in other directions. The linewidth of a "bare" LD is about $\Delta\upsilon$~50 MHz. The output beam is a strongly-diverging elliptical wave. That's because the channel that confines the light is rectangular and of dimensions not much larger than the light's wavelength.

Population inversion isn't achieved at low injection currents since the gain is less than the optical loss. A LED-like light is produced. Above a threshold current, cohesive laser starts to be produced. LD is very efficient compared to other methods in terms of output power/input electrical power, with a ratio as high as 50%.

The linewidth of a bare diode laser ($\Delta\upsilon$ ~ 50MHz) is large compared to those of atomic transitions (Γ ~ Δ5 MHz). They are also very sensitive to feedback that its frequency stability can be affected by as little as 10^{-6} of the output. To solve both

problems, a diffraction grating with a controllable feedback is introduced. It is placed in front of the bare diode such that most of the light is directly reflected by the grating at m = 0 while ~15% of it is reflected back to the laser (m = 1). The grating forms an external cavity that results in a much narrower linewidth (< 1 MHz) and much more stable frequency.

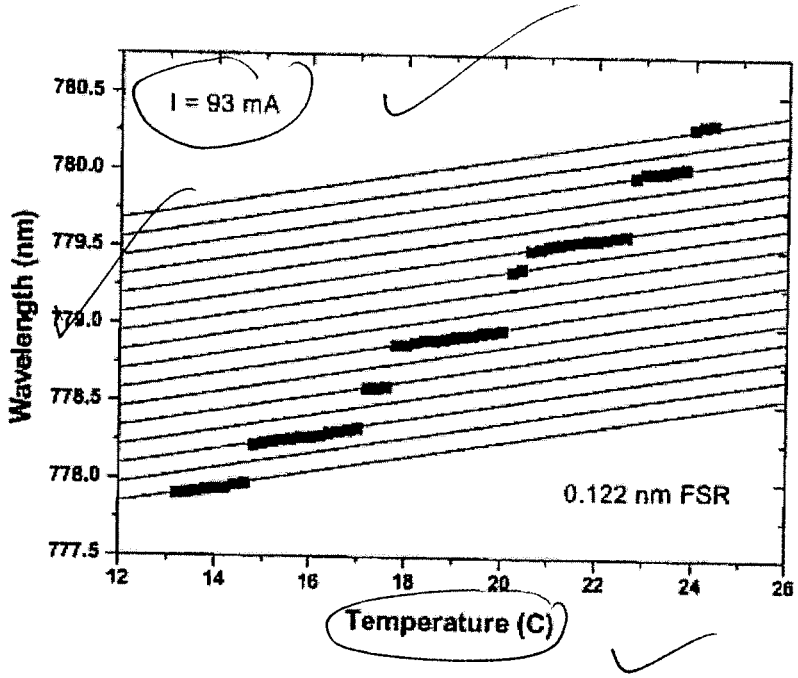
2- Gain and Tuning

With the grating introduced to the system, the laser frequency depends on several factors. Understanding how these factors "combine" to determine the frequency of the laser is helpful for effectively tuning the laser. The laser emits with the greatest gain at the mode frequency. This limits the electron-hole pairs available for lasing in other modes resulting in a single-mode (NOT always). We need to determine the highest net gain in order to determine the laser operating frequency. Figure. 3 shows how each element gain contributes to the net gain.

2.1 The Medium Gain

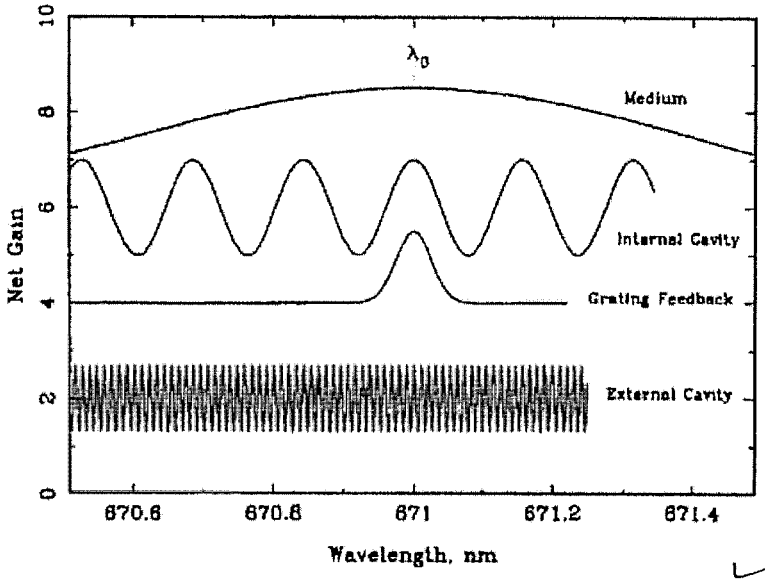
The medium gain depends on the nature of the semiconductor material, particularly its band gap. The medium gain exhibits a broad peak the position of which is mainly temperature-dependent. To produce a laser resonant with Rubidium atomic transitions, we should set the temperature so that it operates at 780nm.

A wavelength vs temperature plot of a typical LD is shown in the figure below. It has an overall slope of 0.23 nm/°C. Knowing the slope and the temperature set point corresponding to 780 nm, we can determine the temperature needed to give any particular wavelength. The medium gain having a broad peak makes it insignificant for the determination of the precise wavelength of the laser.



2.2 The Internal Cavity

As any optical cavity, the diode junction has a normal mode structure, which results in its gain being a periodic function of frequency as shown in the figure below.

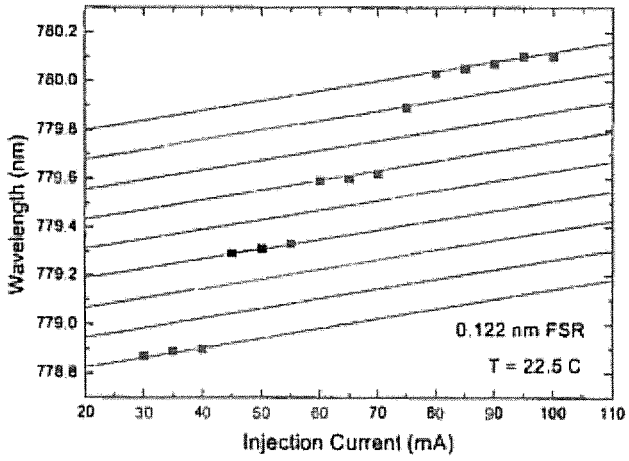


The period, called the free spectral range is given by $\Delta\nu_{FSR} = c/2Ln$ where : c is the speed of light, n is the index of refraction, and L is the cavity length. In our

experiment, $\Delta\nu_{FSR}$ 60 ≈ GHz. The internal cavity gain will change in frequency with changes in temperature with a slope of roughly 0.05 nm $^{o}C^{-1}$, as shown in the small steps in figure (). It's also affected by current in two different ways :

1- Simple heating of the diode. This effect predominates for time scales > 1 μs and tunes at ~ 2 GHz/mA as shown in the figure below.

2- Changing the carrier concentration in the active period. This effect changes the optical path length of the diode, with a tuning rate of ~200 MHz/mA up to a maximum frequency, which is typically up to several GHz.



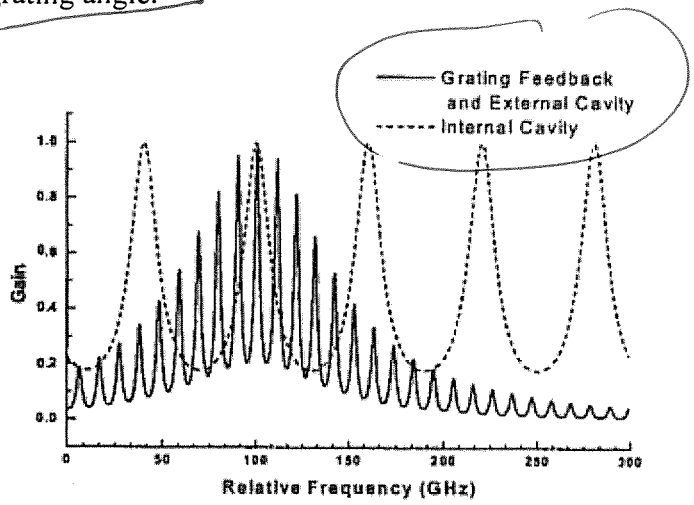
2.3 The Grating Feedback

Because grating disperses light, only a small range of wavelengths is fed back to the laser at a fixed L/R angle. In this apparatus, the first order of diffraction is reflected into the laser. Assuming that diffraction is the only factor in determining the resolving power, the spectral width of the first order diffraction ($\Delta\nu$) is approximated by : $\nu/\Delta\nu = N$, where ν is the frequency and N is the number of grating lines subtended by the laser beam.

2.4 The External Cavity

This is similar to the internal cavity, but, because the external cavity is relatively long, its free spectral range is given by : $\Delta\nu_{SFR} = c/2L \approx 10$ GHz for L = 15 mm. This curve can be shifted by altering the grating position, which can be achieved by either adjusting the L/R knob or by adjusting the piezo-electric transducer.

To get optimal results, we must have the different modes peak at the desired peak λ_0 (See the figure below). This is achieved by adjusting the laser current and the grating angle.



3- Specifications

- Output power : 70 mW
- Wavelength : 785 nm
- Linewidth : < 1MHz
- Grating : 1800 lines/mm

4- Advantages

- Inexpensive.
- Easy to operate.
- Narrow bandwidth ($\Delta\upsilon$ = 1 MHz, $\Delta\lambda = 1.5 \times 10^{-6}$ nm).

c. Other Apparatus

Photodiode Detector :

Photodiodes	Photonic Detectors Model PDB-C108
Active Area	0.25" Diameter Circle
Responsivity	about 0.6 A/W (1.7 W/A) at 800nm
"Gain"*	10 MΩ to 333 Ω

The PD converts current to voltage. They have gain choices of 10 MΩ to 333 Ω in 10 steps.

Absorption Cell Assembly :

The absorption cell assembly consists of an outer glass cylinder, several melamine foam insulation and support pieces, the heater assembly, a type T thermocouple sensor, a cold-finger, and the Rb cell. The heater is an aluminum cylinder about which is wound a bifilar heater wire. The heater has a resistance of about fifty ohms (50 Ω). Wires from the heater and thermocouple plug into the back panel of the electrical box.

SPECIFICATIONS

Maximum temperature	≈ 90 °C
	≈ 140 °C with ½" hole foam inserts
Temperature differential across Cell	
T= 50°C (min. on bottom max. on top)	10 °C
	2.0 °C with ½" hole foam inserts
Heater resistance	≈ 50Ω
Temperature Controller	1 Hz PWM* PID
Controller Resolution	0.1 °C
Regulation (no air currents)	0.2 °C
Rubidium Cell	25 mm Diameter and 25 mm Length natural isotopic Rb. (no buffer gas)

Magnetic Field Coils

The coils in this experiment were designed to give B ≈ 10 mT at I = 3 A and with specifications :

Average Coil Radius : 87.4 mm

Number of turns : 320

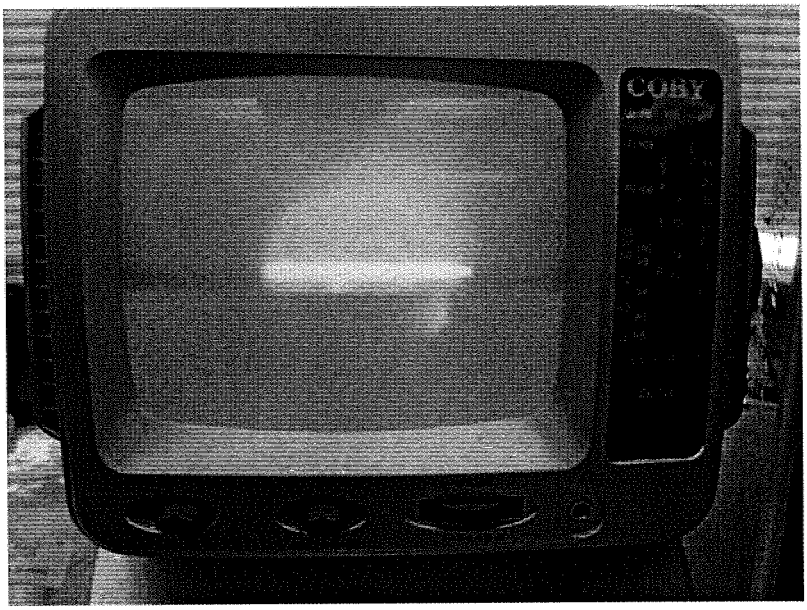
Room temperature resistance : 4 Ω

50/50 Beam Splitter

The 50/50 beam splitter was coated such that it has a reflection of 50%. It must be noted, however, that this is only ideal for unpolarized light, as reflection is polarization-dependent.

TV and Camera :

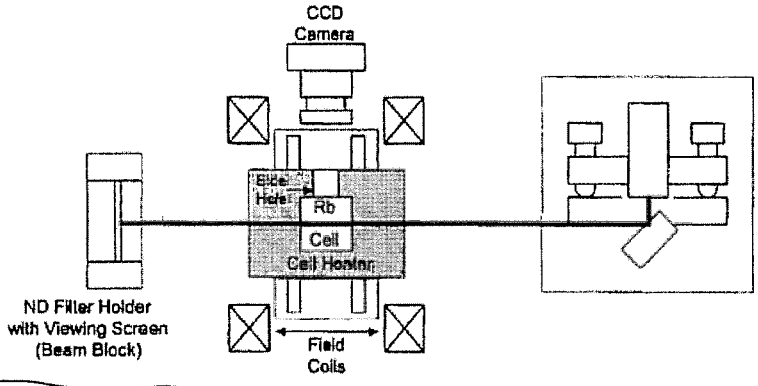
The TV and Camera are used to detect "flashes" which indicate the absorption process, as seen below.



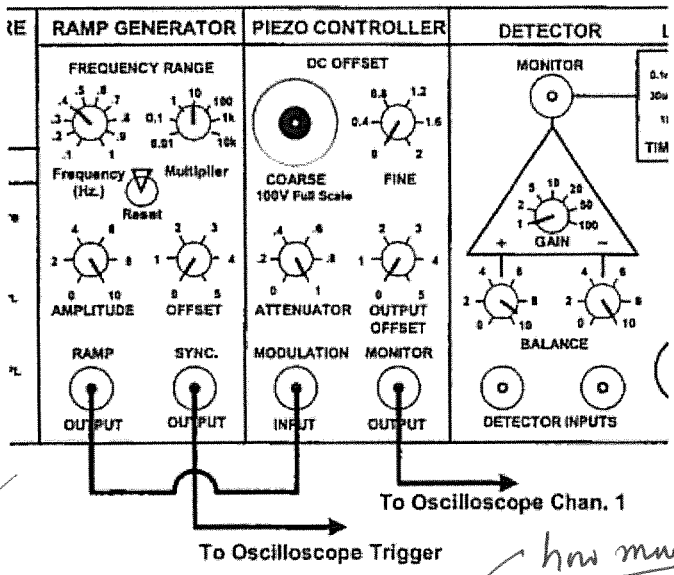
III. Procedure

1- Checking Temperature : We first checked that the temperature of the cell is the optimal temperature for this experiment, which is 50 °C.

2- Set-up and alignment : We sat the experiment components as shown below and checked the alignment of the laser using IR card. (More details in appendix).

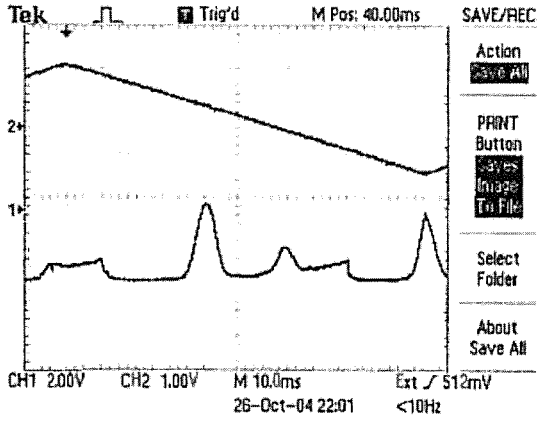


3- Connecting different parts : We connected the different apparatus as shown below

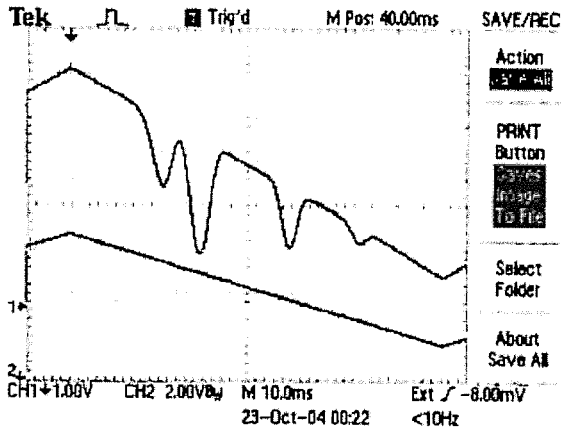


4- Initiating absorption process : We connected the LASER CURRENT MONITOR to a voltmeter in order to monitor the laser current and make sure that it is above the threshold current listed on the data sheet. To check that the absorption process actually started, we used the camera to observe a stream of "pulses".

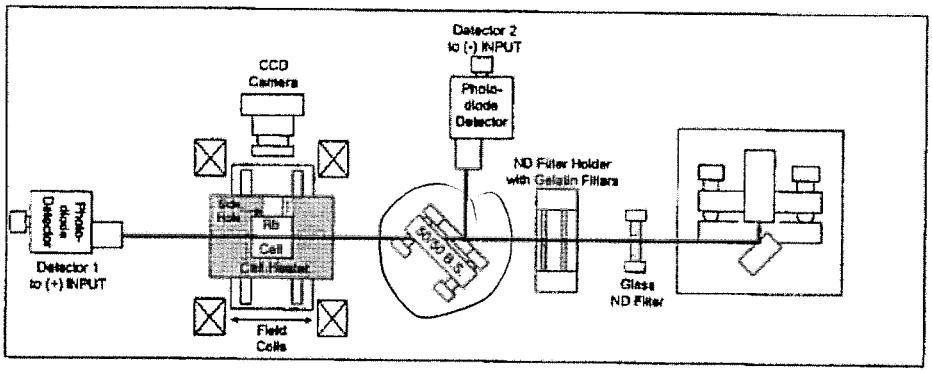
5- Detecting the PD signal : We placed a photodiode detector (PD) in a place such that it detects the waves leaving the absorption cell. Then, we connected the PD to the DETECTOR POWER output of the laser controller and the PD output to channel 2 in the oscilloscope. We sat the gain of channel 2 to 5 V/div. We placed an attenuator between the laser and the Rb cell. Adjusting the PD gain, we tried to get a signal similar to the figure below in the 'scope.



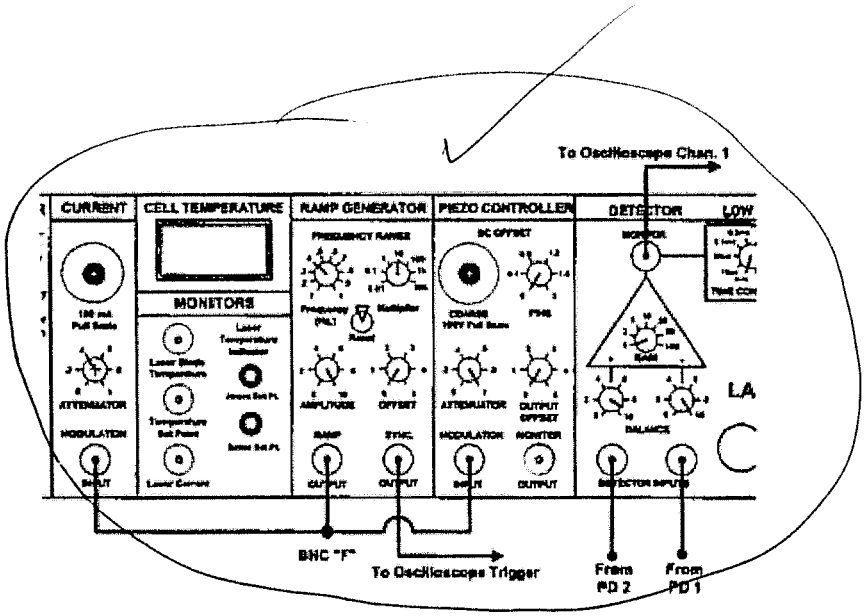
To further refine the signal, we played with current attenuation and piezo controller. The goal was that, after inverting the signal, we get a signal similar to this.



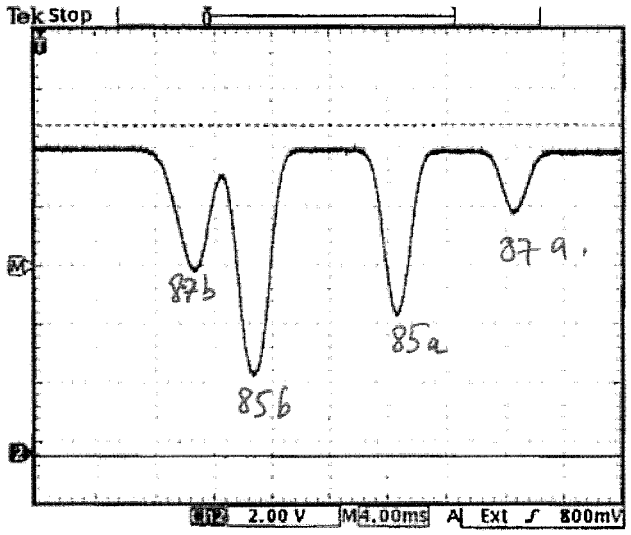
5- Reducing the background noise: To reduce background noise, we needed to simultaneously detect two signals : One prior to the absorption process and one after it. To do that we placed a 50/50 beam splitter between the laser and the Rb cell, and placed a detector to receive the split waves, as shown below.



Then, we connected PD 1 to the rightmost DETECTOR INPUT in the laser controller and PD 2 to the leftmost DETECTOR INPUT. We then connected the MONITOR to one of the oscilloscope channels.

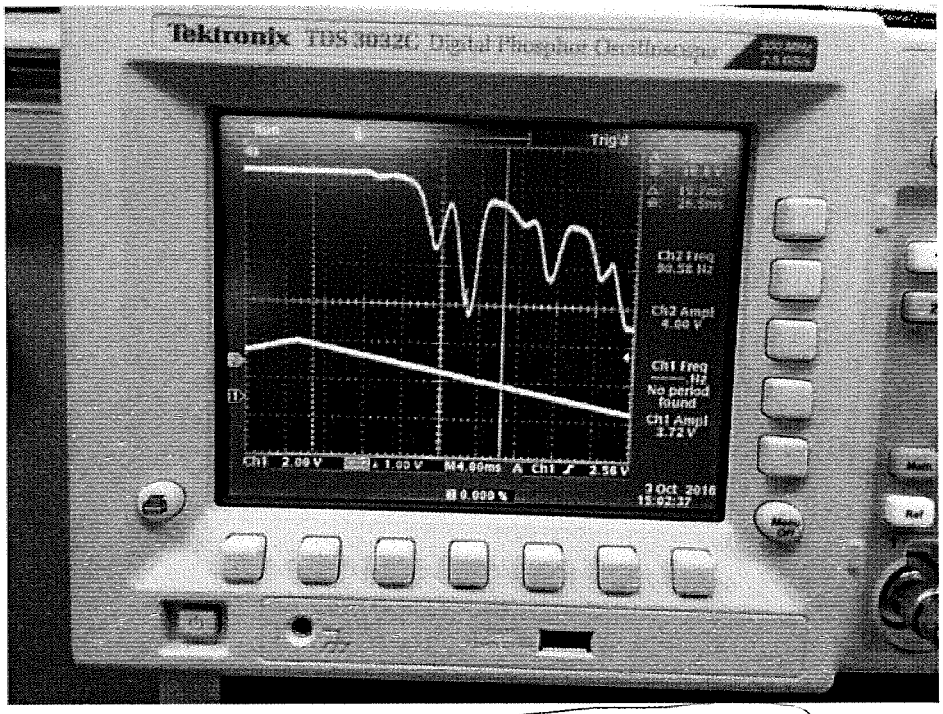


Adjustig the BALANCE knobs of the two detectors, as well as the previously used controllers (laser current, Piezo controller, ... etc), we tried to get a signal close to the one in the figure below.

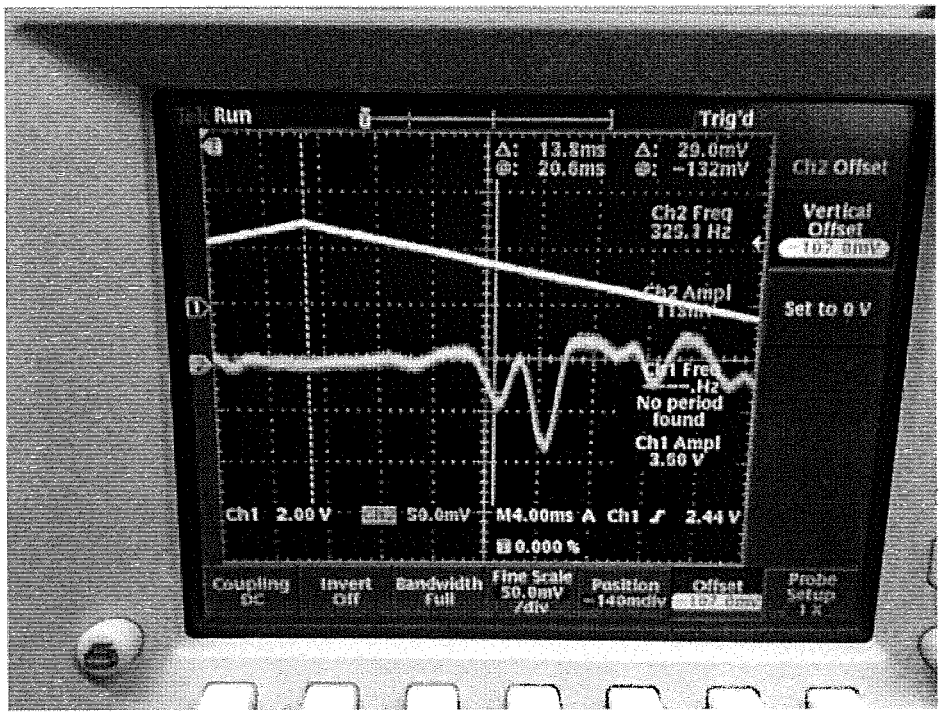


IV. Results

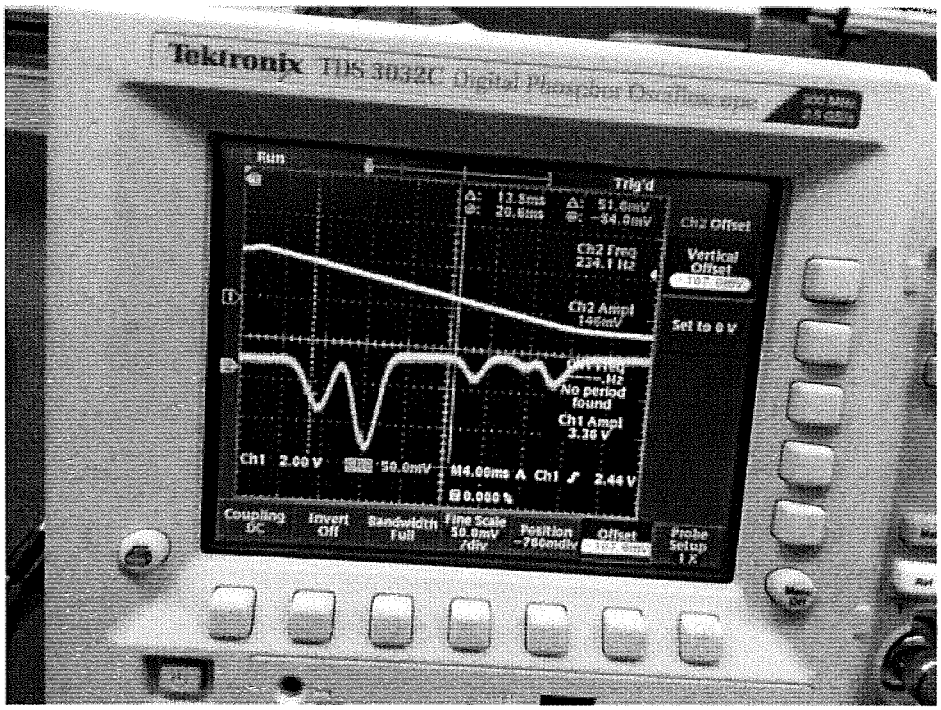
"Raw" one-detector signal of Rb absorbtion :



Two-detector (reduced noise) signal before modification:



Two-detector signal after modification of balance, attenuation … etc. :



V. Conclusion

Rubidium has two major (and two minor) absorption dips corresponding to its two isotopes : ^{85}Rb ^{87}Rb.

* Level diagram of Rb. isotopes peaks

your findings ??

* Comparison of signal with the theoretical results

Al-Shamiri

NMR

Exp #4

Phys403 Report Format T161

Phys403 Report Evaluation Criteria (Total Points =75)

(Report Contents and associated grade points)

☐ **Title page**	**2/75**
• **Title of the experiment**	2
• **Course name and term**	
• **Name of student and ID number**	
• **Name of supervisor**	
• **Date of submission**	
☐ **Table of contents page**	
☐ **Abstract**	2 **4/75**
• Brief summary of the technique used and main findings.	
☐ **Introduction** 2-7 pages (td = 18) too much	11.6 **10/75**
• Background including, basic principle and theory, a brief review of literature.	
☐ Objectives	2 **5/75**
☐ **Experimental details**	15 **20/75**
• Description of equipment	
• Sample preparation	
• Description of methods used.	
☐ **Results and Discussion**	20 **25 /75**
• States the results of the research. y axis on the wrong side	
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48/75

Nuclear Magnetic Resonance (NMR)

Exp #4

Jan 1

Course: Phys403

Term: 161

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Instructor: Dr. Akhtar Naqvi

Date: 12/30/2016

Table of Contents

Abstract:

Nuclear Magnetic Resonance (NMR) spectroscopy is an analytical technique used in chemistry (quality control) and biology. Moreover, it is used in research for determining the content, purity of a sample, and molecular structure. The intramolecular magnetic field around an atom in a molecule changes the resonance frequency, so we can get to details of the structure of a molecule. In this experiment we will determine the spin lattice time and spin-spin time for heavy mineral water and glycerin.

Introduction:

Objectives:

the main objectives in this experiment is to get used to the equipment and the nuclear process and interaction that is related to magnetism and electricity. To be exact the objective is identifying the properties of FID decay curve for different sample. Then to decide this relation using T1 and T2 and other factors.

Background and Theory:

NMR is utilized to achieve excitation between two different spin states of nucleus. The process imitates the natural magnetism that is generated by the nucleus

rotating about itself. This stimulation gives this equation:

$$\mu=\gamma I$$

where I is the magnetic momentum and μ is the magnetic moment. The magnetic field is produced along the z-direction and modified using the component along x,y,and z components of the magnetic field. This can be calculated using the following relation:

$$\gamma=ge/(2m_p)$$

where g is the spectroscopic splitting factor, e is the electron's charge (1.6*10^-19), and m_p is mass of proton. These relations are due to no external field. However, in presence of an external field B_o we get a torque that rotates the nucleus due to μ. The mechanism of the rotation is as follows the nuclear magnetization presses along the z-axis with a specific frequency called the Larmor frequency which is given by:

$$\omega_o=\gamma B_o$$

because the magnetic field $\mathbf{B_o}$ splits the spin will split into two levels with I=0.5 and -0.5 with energy difference given by:

$$\Delta U=\gamma \hbar B_o$$

When a transition from the upper to a lower energy level happen the emitted photon is ruled by this relation:

$$\hbar\omega_o=\gamma \hbar B_o$$

Where the frequency is the dependent variable and the one that we will manipulate to get the signal. The RF generator circuit produces the applied magnetic field. The frequency should be in the range of MHz to make a change that can be detected. This magnetic field should be circularly polarized and in the same precision with the angular spin to change the magnetic spin and the frequency. To maximize the probability that the spin will be excited (from 0.5 to -0.5) make the magnetic field processing with the same frequency as the magnetic moment and decrease as the frequency changes. The magnetization can be measured by measuring the net effect on all the spins. In most of the times the effect is not notable therefore the magnetization becomes zero. In other occasions there are some remains that can be calculated by the following ration:

$$N_+/N_-=\exp(-U_+/kT)/\exp(-U_-/kT)=\exp(\gamma \hbar B_o/(kT))$$

The equilibrium achieved by the above formula is disturbed if there is an external magnetic field. However

shortly after that it will return to its original position. The magnetization can return to its original position if the field is oscillating but not constantly applied because the protons continuously exchanges the energy and magnetization with the surroundings. Since the moment of the anti-parallel is more than the moment of the parallel the z-component of the magnetization is always different from zero. The time that M_z returns to its equilibrium position is called the spin relaxation time (T1). M_x and M_y oscillates with the average at zero. If an excitation happens to one of the component it will return to its orginal position in a time alled spin-spin time (T2). The direction of the generated voltage is given by the cross product of the magnetization with the magnetic field by faraday's law we have:

$$\varepsilon = -d\phi_B/dt$$

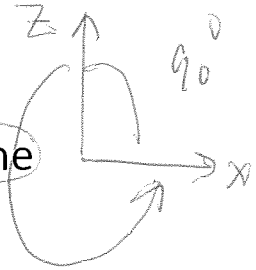
In calculating the difference in the magnetic field magnitude and direction the mean will be the voltage. If the magnetic field starts to rotate we will have two spin time, the spin-spin time will be for the x-axis and y-axis the other is spin-lattice time for the z-axis. If the magnetic field is inhomogeneous a third one will emerge which result in spin-spin dephasing time. The z-component of the magnetic field is rotating in the Larmor frequency to achieve optimal uniformity. The relation between the three relaxation time is given as follows:

$$1/T_3=1/T_1+1/T_2+\gamma\Delta B_o$$

1/T3 is the best width for the resonance frequency. T1 and T2 is the best way to describe the characteristics of the magnetic field behavior of the sample used. There are many ways to find them as we will see in this report. There are three components for the main magnetic field, we will find the difference of the relaxation with respect to time from the resonance frequency of precession.

Experimental Details:

In this experiment we will utilize a sample under external magnetic field either a constant one or rotationally varying one to study different aspects of the behavior of the material used. To control the magnetic field component in all direction different coils will be used. To have control over the frequency of the magnetic field of the nucleus electric current of oscillating nature is generated from the coil. The application of consecutive beats or pulses make this control. The two essential pulses are the toyes 90 and 180 degree pulses. The 90-degree pulse responsible for



the rotation of the magnetization from the z-axis to the x-axis whereas the 180-degree pulse rotates the magnetization to the opposite side of the same axis. A precision occurs here is the transformation of the coordinates system in order to be in the same reference frames with the rotating magnetic field B_o which will eventually disappear. The new coordinates system is given by:

$$x' = x\cos(\omega_o t) - y\sin(\omega_o t)$$
$$y' = x\sin(\omega_o t) + y\cos(\omega_o t)$$
$$z' = z$$

What is this

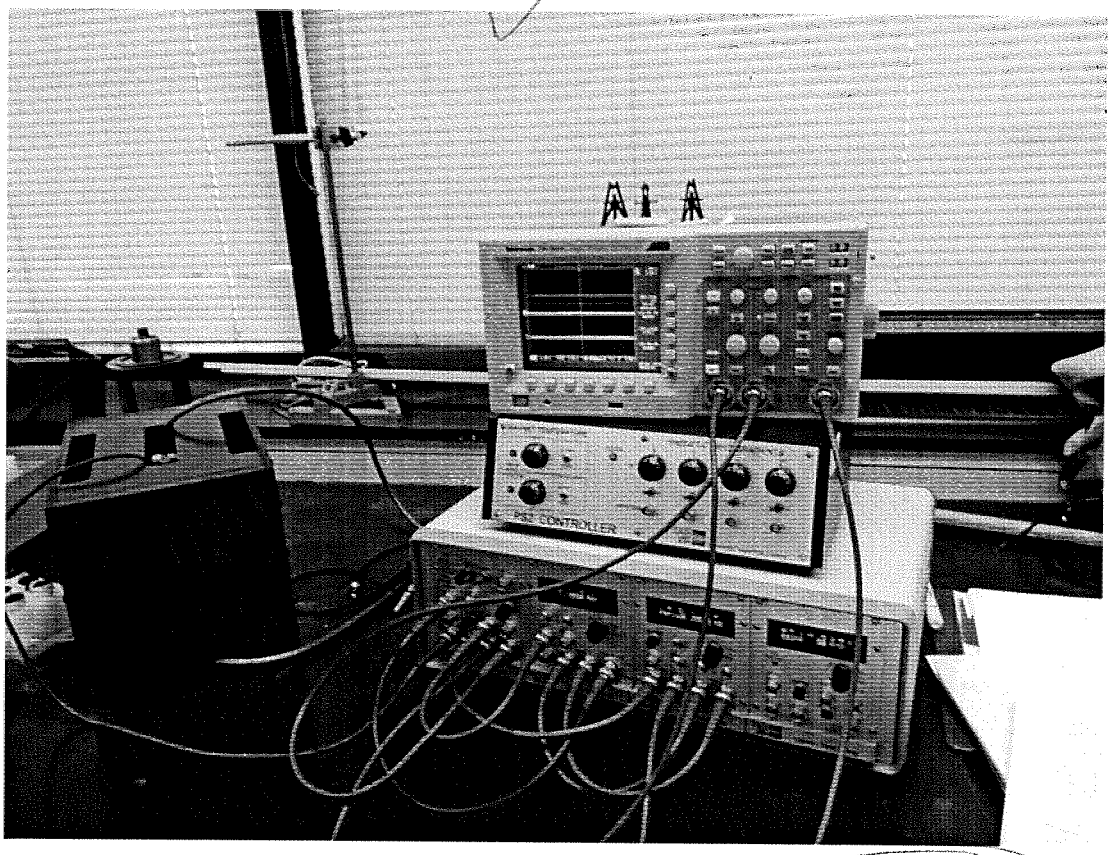
B1 will appear as a constant because it is applied to maintain the same coordinate system. In a bulk of moments, the initial position of the magnetic field will be in the z-axis then it will process around the z-axis a voltage will be induced that is detected by the coil and called free induction decay (FID). This is one form of the 90-degree pulse. The magnetization M_o of the sample depends only on the following:

$$M_o = N\mu^2 B/(kT)$$

Where μ is the magnetic moment, B is the magnetic field, k is Boltzmann constant and T is the temperature. The next relation describes the builds of the magnetization from zero to the equilibrium point:

$$M_z(t)=M_o(1-\exp(1/T_1))$$

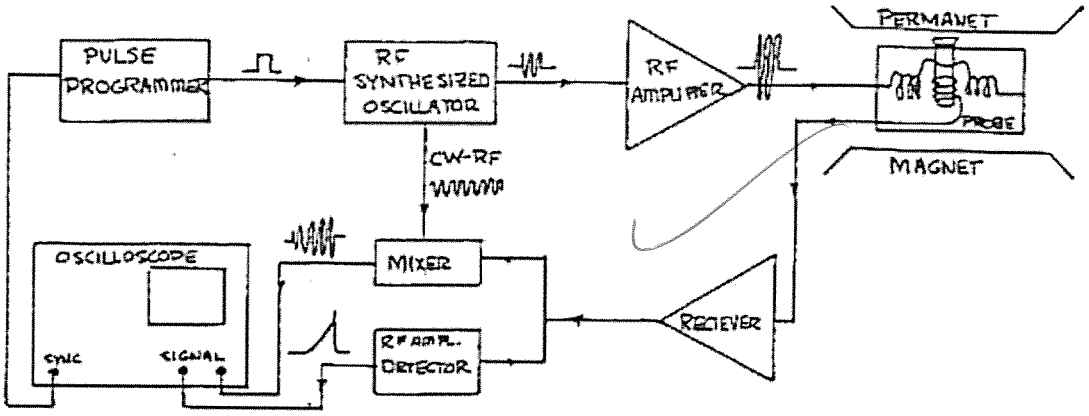
Apparatus:



There are several components that the 90-degree pulse depend upon in this apparatus:

$$t_{\pi/2}=\pi/(2\gamma B_1)$$

the important components are the RF generator, magnetic coils, receiver, pulse programmer, lock in the amplifier, and synthesizer.



RF generator:

We will pass a current with varying frequency depending on the RLC circuit in the coil that itself produce a varying magnetic field in the same frequency. The RF generator have a specific frequency where we can obtain the minimum and other frequency where we can obtain the maximum. Moreover, the pulse programmer controls the phase.

Magnetic coil:

The magnet utilized in this experiment are the different permanent magnets with gradient controlling the different axis. The main reason it is used is to control the FID signal generated by the sample which is surrounded by the coil in the loop. We can separate the coils into three main parts horizontal, vertical and gradient which manipulate the magnetic field as desired.

Receiver:

It receives the signal from the magnet and transfer it toward the pulse programmer in an understandable

form to the synthesizer. The form can be obtained using RC filters to smooth the signal

Pulse Programmer:

Most of the work is done here, the pulse can be adjusted in terms of phase, frequency and other factors. The objective of the manipulation done to the pulse is to get the best signal to send it to the oscilloscope. The I and Q signals are produced in this part by applying some transformation.

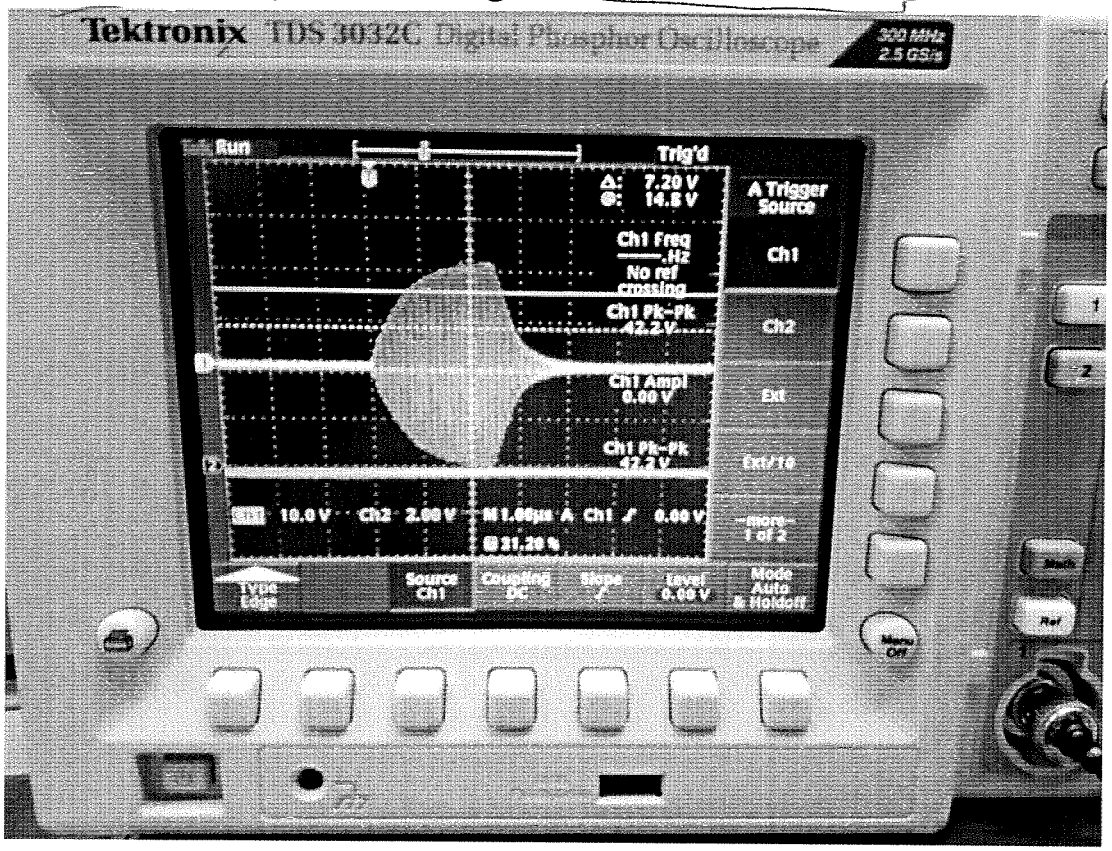
Signal Synthesizer:

In this part the signal is transported to the oscilloscope in different forms with several properties. The properties are controlled in the synthesizer as time difference, signal length and number of signals. Moreover, information from the pulse programmer is received and sent to the Lock-In Amplifier's by the signal synthesizer which act as a transformer.

Procedure:

The main goal of this experiment is to verify the behavior of the heavy mineral oil and the glycerin. Since

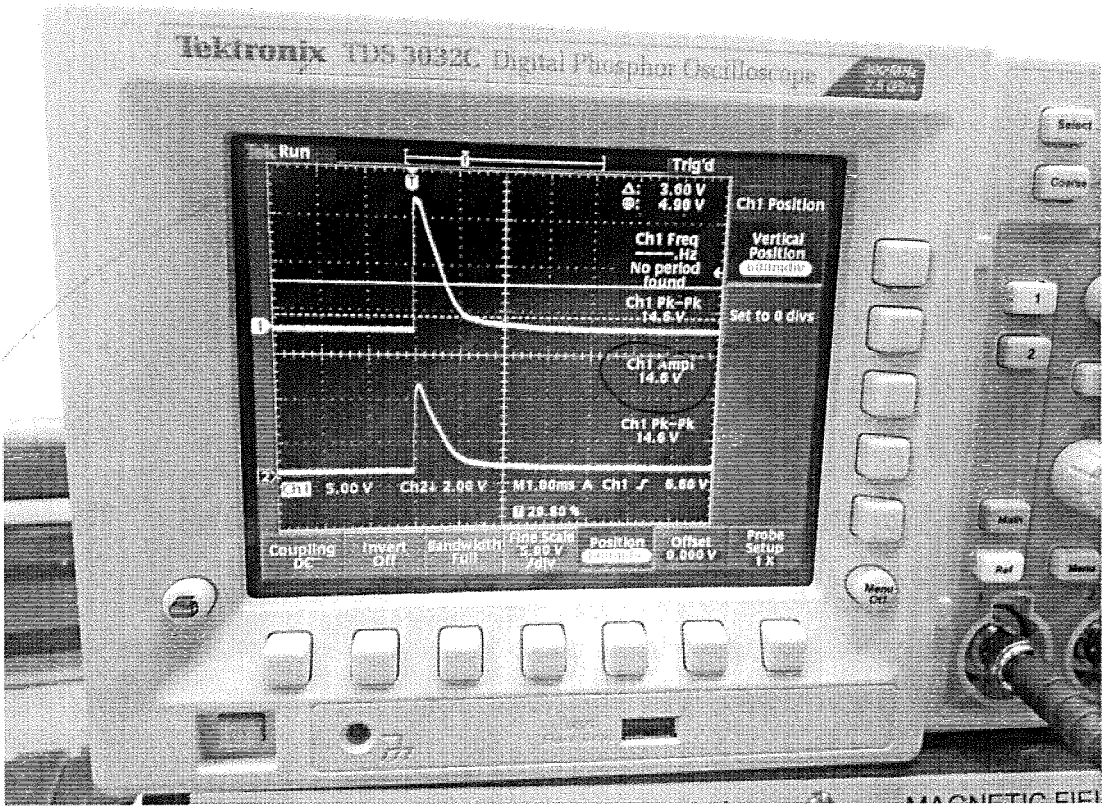
the machine is complicated and involved several apparatus as presented earlier the setup took a long time. Then we operated the machine, after that before putting the sample we tune the detector using the tubing capacitor to get the possible signal for the FID later. The shape of the signal must be similar to this:



Then we search for the highest amplitude frequency which will be approximately 21.6-21.4 MHz. Because at the resonant frequency all the components of the magnetic field are minimum except for the z component this phenomenon arises. This result in the maximum rotation. There are some extra set up of some conditions in the apparatus to measure the signal properly like tunings and checkup of the wires which is important for operating the experiment.

Finding T_1 and T_2 for light mineral oil and glycerin:

Adjust the period as given for the sample. Make sure that there is a separation of 39mm from the center of the sample to the lower edge of the O ring, then place the tube in the magnets. Thereafter, make sure that ch1 is connected to Env out from the receiver and on the pulse programmer toggle sync to A, A pulse to on, and B pulse to off. After that set the oscilloscope sweep time too 1ms/div. manipulate the scaling as necessary, consequently play with the frequency till you get a decay shape. Then adjust the four gradient component until you get the best decay shape, the decay shape should be similar to this:



The maximum of the A pulse gives the 90-degree pulse length whereas the 180-degree length happens when

you increase till the signal disappears. Then put A to the 180-degree pulse and B to the 90-degree pulse and put the number of pulses to 1 and sync the toggle switch to B and set the B pulse to on. Next, pick ten values from the range given for τ for the chosen sample and record the values of M(τ), we can obtain M_{eq} by getting τ to a high value which produce a maximum peak. These are the sufficient data to get T_1. We can obtain T_2 by following similar technique used to find T_1 only with a small exception that is to change the pulse sequence. The relation between M_{eq} and M(τ) is given by:

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

where M_{eq} is the equilibrium magnetization, M is the magnetization, and τ is the time separation between the signals.

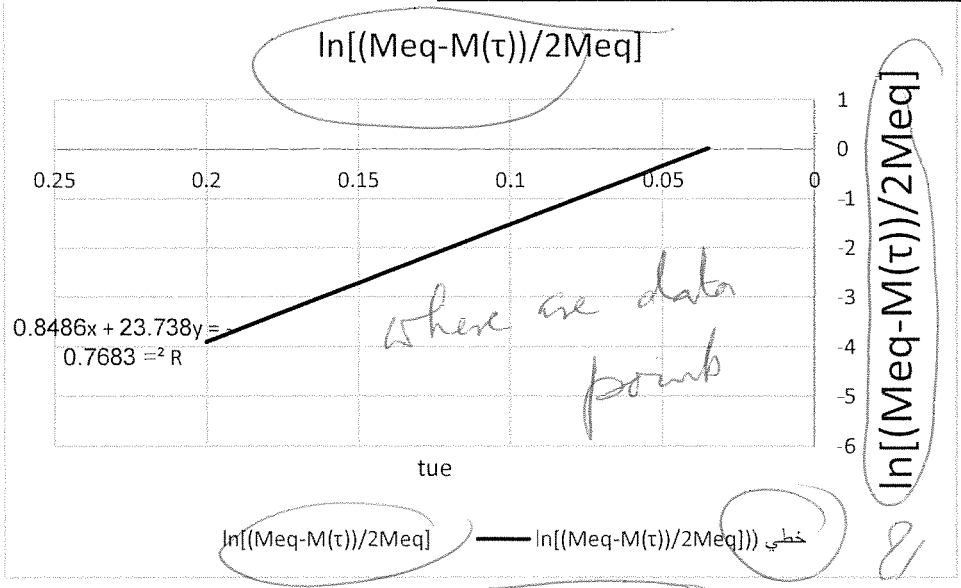
Result and Discussion:

Light mineral oil Data:

For T_1

ln[(Meq-M(τ))/2Meq]	Meq	Mτ	τ(s)
-0.728738126	14.3	0.5	0.035

-0.780794488	14.3	1.2	0.05
-0.876868318	14.3	2.4	0.065
-0.983162976	14.3	3.6	0.08
-1.050821625	14.3	4.3	0.095
-1.167355441	14.3	5.4	0.11
-1.393311934	14.3	7.2	0.125
-2.045073898	14.3	10.6	0.14
-2.323787301	14.3	11.5	0.155
-2.822778467	14.3	12.6	0.17
-3.458767233	14.3	13.4	0.185
-5.655991811	14.3	14.2	0.2



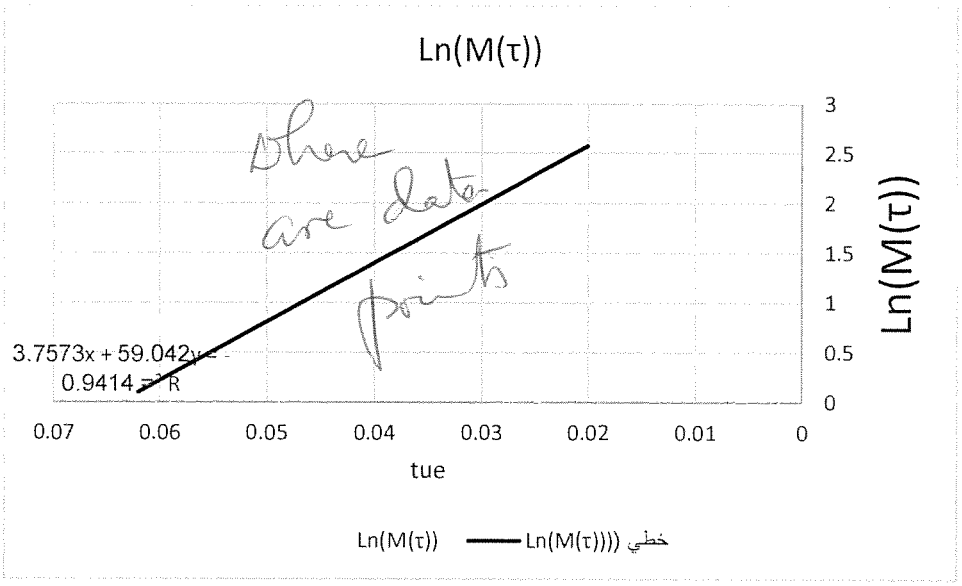
where are data points

Wrong hide Axis

Therefore, T_1=-1/-23.738=42.13ms

For T_2:

Ln(M(τ))	Meq	Mxy(τ)	τ(s)
2.282382	14.3	9.8	0.02
2.174752	14.3	8.8	0.026
2.014903	14.3	7.5	0.032
1.856298	14.3	6.4	0.038
1.386294	14.3	4	0.044
0.641854	14.3	1.9	0.05
0.336472	14.3	1.4	0.056
0	14.3	1	0.062

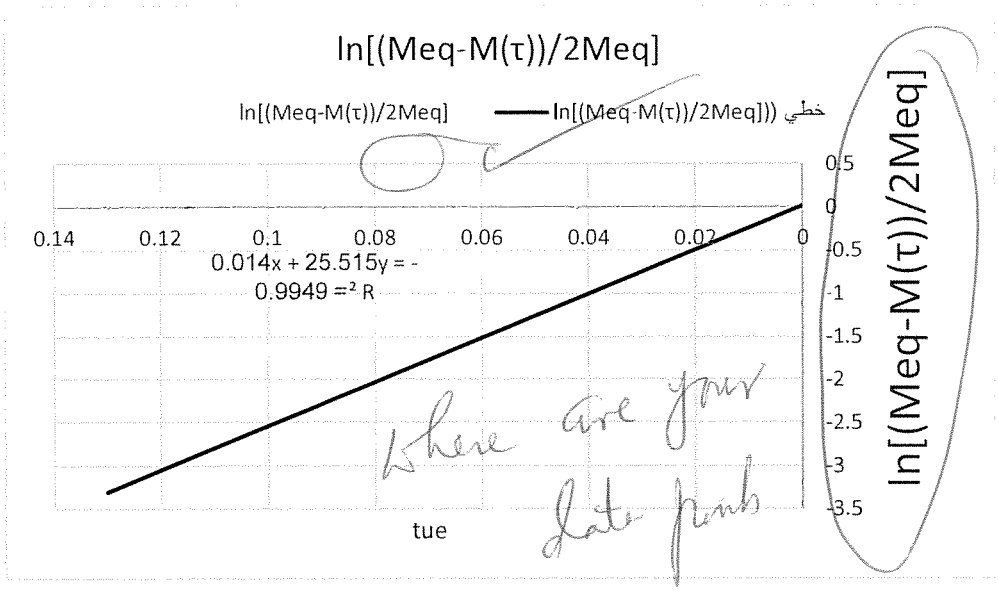


T_2=-1/-59.042=16.94ms

Glycerin Data:

For T_1

ln[(Meq-M(τ))/2Meq]	Meq	M(τ)	τ(s)
-0.003944778	12.7	-12.6	0
-0.114589322	12.7	-9.95	0.005
-0.214324288	12.7	-7.8	0.01
-0.316978442	12.7	-5.8	0.015
-0.431388793	12.7	-3.8	0.02
-0.550308839	12.7	-1.95	0.025
-0.809946448	12.7	1.4	0.03
-0.983457375	12.7	3.2	0.04
-1.233269174	12.7	5.3	0.05
-1.586090548	12.7	7.5	0.06
-1.8237622	12.7	8.6	0.07
-2.136136885	12.7	9.7	0.08
-2.401840051	12.7	10.4	0.09
-2.646962509	12.7	10.9	0.1
-2.764745545	12.7	11.1	0.11
-2.97238491	12.7	11.4	0.12
-3.139438994	12.7	11.6	0.13



Where are your data points

Wrong scale of the graph

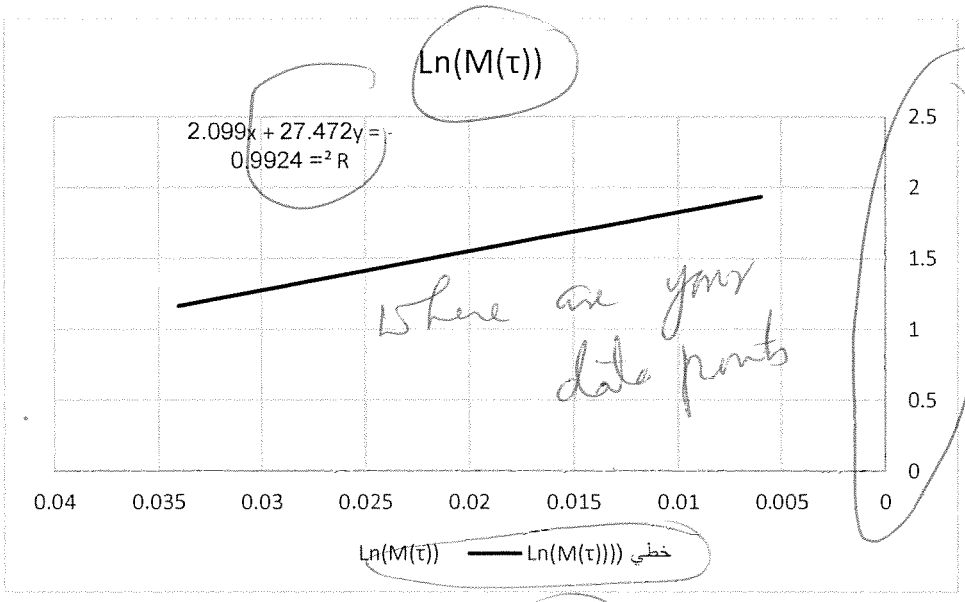
T_1=-1/slope=39.2ms

For T_2:

$\ln[M_{xy}(\tau)/M_{eq}]=-\tau/T_2$

unit

Ln(Mτ)	Meq	Mxy(τ)	τ(s)
1.94591	12.7	7	0.006
1.824549	12.7	6.2	0.01
1.722767	12.7	5.6	0.014
1.589235	12.7	4.9	0.018
1.504077	12.7	4.5	0.022
1.335001	12.7	3.8	0.026
1.280934	12.7	3.6	0.03
1.193922	12.7	3.3	0.034



Where are your data points

Wrong side of axes

Therefor T_2=-1/-27.472=36.4ms

Conclusion:

The data that are collected using the NMR experiment are essential for the medical, nuclear, and chemical use. It is the underlying concept that MRI depend upon. The experiment gives you the knowledge of the operation of the NMR. We mainly conclude from this experiment the

role played by the Larmor precession mechanism in the nucleus itself rather than in the atom.

What about your findings??

References:

-wikipedia
-glycerin-Sandeigo-NMR
-mineral-oil-brandies

Exp #1

Phys403 Report Format T161

ESR

Phys403 Report Evaluation Criteria (Total Points =75)

(Report Contents and associated grade points)

- ☐ **Title page** — **2/75**
  - **Title of the experiment**
  - **Course name and term**
  - **Name of student and ID number**
  - **Name of supervisor**
  - **Date of submission**

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- ☐ **Table of contents page**

- ☐ **Abstract** — **4/75**
  - Brief summary of the technique used and main findings.

0

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  - Background including, basic principle and theory, a brief review of literature.

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- ☑ Objectives — **5/75**

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- ☐ **Experimental details** — **20/75**
  - Description of equipment
  - Sample preparation
  - Description of methods used.

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- ☐ **Results and Discussion** — **25 /75**
  - States the results of the research.
  - Data analysis
  - Discussion of results

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- ☐ **Conclusion** — **5/75**
  - Summary of results and main findings.

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- ☐ **References** — **4/75**

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5

DEPARTMENT OF PHYSICS

Exp #1

Senior Physics Laboratory-(PHYS403)- Autumn 2016
(Term 161)

Lab/ Electron Spin Resonance

Name/ Shabeeb Al-alawi
ID/201246360

OBJECTIVES:

- looking for the "spin-flip" transition of a free (unpaired) electron exposed to a magnetic field.
- Measure g, a dimensionless quantity that relates the difference in energy between two levels and the magnetic field present.

I-INTRODUCTION & THEORY:

Electron spin resonance (ESR) is a very powerful and sensitive method for the characterization of the electronic structures of materials with unpaired electron. ESR has been advanced to significant method of investigating molecular and crystal structures, chemical reactions and problems in physics, chemistry, biology and medicine. The molecules of a solid (or sample test) exhibit paramagnetism as a result of unpaired electron spins, transitions can be induced between spin states by applying a magnetic field and then supplying electromagnetic energy, usually in the microwave range of frequencies. The sample is also wrapped within a coil that is connected to an RF oscillator. (Figure 1).

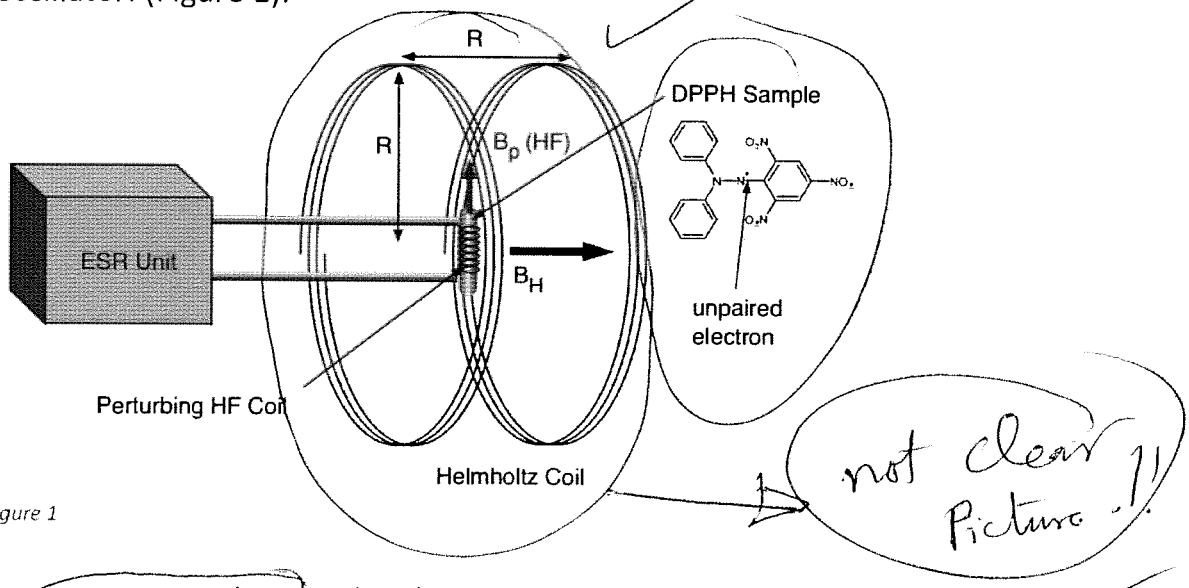


Figure 1

From quantum mechanics, the electron has a magnetic dipole moment (μ_s) that is related to its intrinsic angular momentum, or spin, by the vector equation:

$\mu_s = g_s u_B (S/\hbar)$

g_s =a constant characteristic of the electron, the g-factor

μB =the Bohr magneton = eh /2mc =5.788 x 10–9eV G

S =the spin of the electron

$\hbar$ =Planck's constant = 6.582 x 10–16 eV-sec

Because of its quantum nature, the electron can orient itself in one of only two ways, with energies equal to $E_0 = \pm g_s \mu B/2$ where E_0 is the energy of the electron before the magnetic field was applied. The energy difference between

these two possible orientations is equal to $g_s \mu_B B$; where B is the magnitude of the magnetic field.

The basic job of the RF oscillator is to adjust a frequency v, in order to let the energy of the irradiated photons, hv, is equal to the difference between the two possible energy states of the electron. Electrons in the lower energy state can then absorb a photon and jump to the higher energy state. If we look deep in our situation, when an electron is placed in a magnetic field, the degeneracy of the electron spin energy levels is lifted and there are two energy states for this electron, as illustrated in Fig. 2. The energy levels are easily found by application of the spin Hamiltonian to the electron spin eigenfunctions corresponding to $m_S = \pm 1/2$

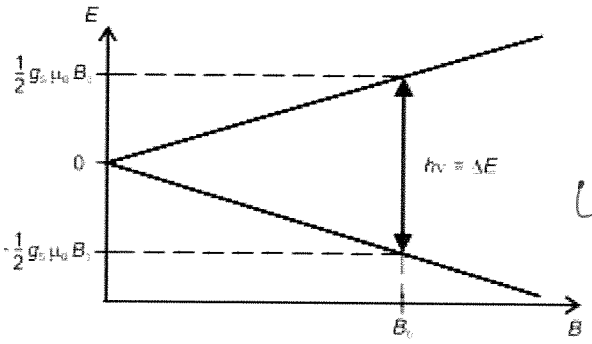


Figure 2

$$\hat{H}_s \left|\pm 1/2\right\rangle = \pm \frac{1}{2} g\mu_B B \left|\pm 1/2\right\rangle = E_\pm \left|\pm 1/2\right\rangle$$

Thus $E\pm = (\pm 1/2) g\mu_B B$

The difference in energy between the two levels: $\Delta E = E_+ - E_- = g u_B B$, which corresponds to the energy of a photon required to cause a transition:

$h\nu = g u_B B$.

If the RF frequency in the last equation is satisfied at some point between the minimum and maximum values of the sinusoidally varying magnetic field, then resonance will occur twice during each cycle of the field. Furthermore, EPR spectra can be generated by either varying the photon frequency incident on a sample while holding the magnetic field constant or doing the reverse. In practice, it is usually the frequency that is kept fixed. On other words figure 2 indicates when the energy hv of the alternating field is equal to the energy difference ΔE between two neighboring energy levels, the alternating field leads to a "flip" of the magnetic moments from one orientation in the magnetic field B into the other one.

II-EXPERIMENTAL PROCEDURE:

I started the experiment by looking into the ESR Apparatus:

The ESR Probe Unit: Provides all required voltages and also digitally indicates the frequency of the oscillatory circuit. It includes The Probe Unit with base Three, RF Probes and a DPPH sample in a vial, the Passive Resonant Circuit and the Current Measuring Lead for the Probe Unit.

The ESR Adapter: can be used to connect the Probe Unit to the necessary power supply, frequency meter, and oscilloscope (included in the ESR Basic System, but not in the Complete ESR System).

A pair of Helmholtz Coils with bases: deliver a highly uniform magnetic field in which to place the sample material for the ESR measurement

The Control Unit: provides most of the instrumentation needed to use the ESR Probe Unit. It supplies the voltages needed to drive the Probe Unit and the Helmholtz coils; it provides a digital readout of the RF oscillations produced by the Probe Unit; it provides outputs for a dual trace oscilloscope.

Oscilloscope: display and analyze the waveform of electronic signals.

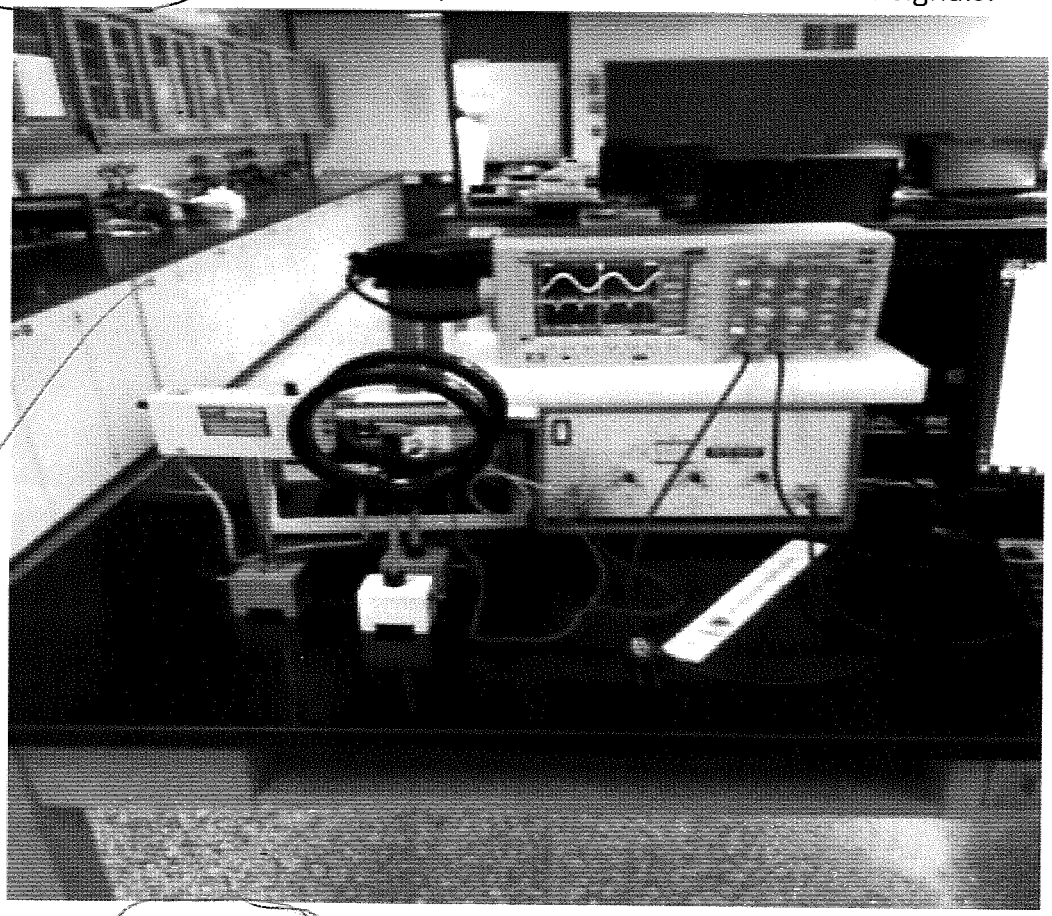


Figure 3 The ESR Apparatus

Figure 3 has been taken from the lab on the instruments that I was working on it.

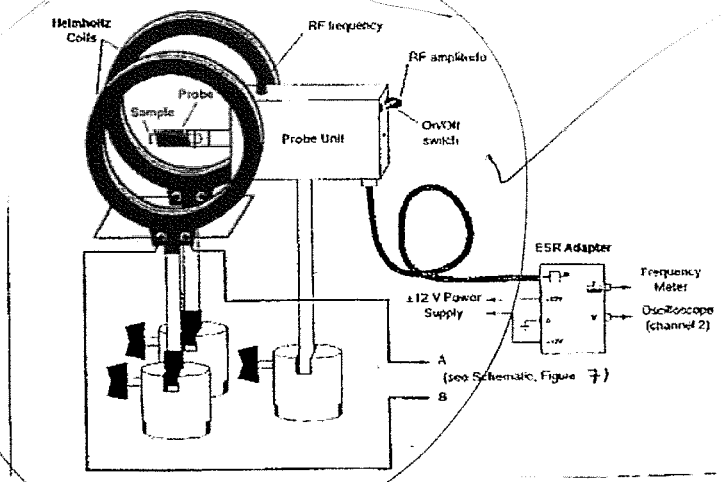


Figure 4

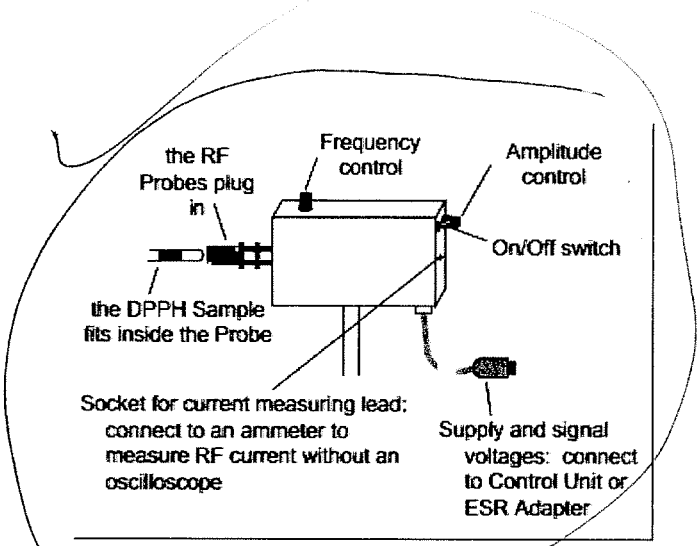


Figure 5 ESR Probe Unit

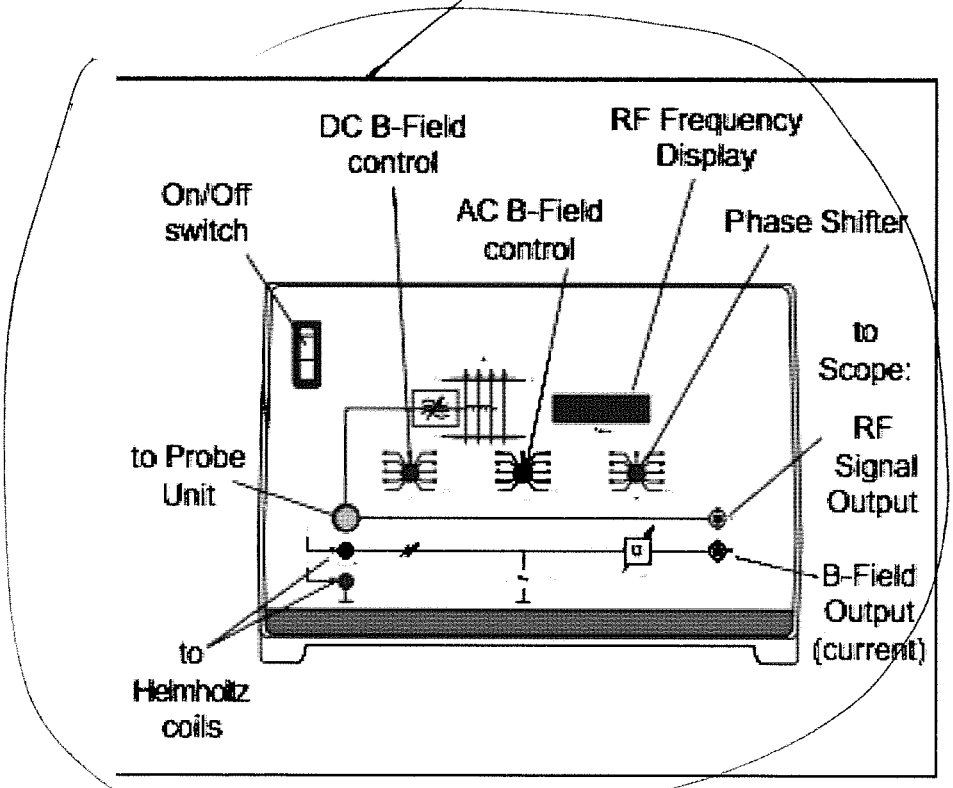


Figure 6 ESR Control Unit

After checking the Apparatus, I started working:

1-I connected the helmholtz coils to the Control Unit (The coils were connected in parallel—terminal A to terminal A, and Z to Z.) and put them in parallel and facing in the same direction, and their separation was equal to approximately one half their diameter.

2-I Connected the X output of the Control Unit to channel 1 of a dual trace oscilloscope.

3- In the Control Unit, I set U_{mod}, the center knob to zero, then slowly vary U_0, the left knob, from 0 to 10 V and to observe the trace on the oscilloscope. (U_0 controls the DC current going to the Helmholtz coils.)

4- I set U_0 at approximately midscale, then I turned U_{mod} clockwise, to increase the AC component of the current to the Helmholtz coils. The trace on the oscilloscope was a smooth sine wave.

5- I added the Y output of the Control Unit to channel 2 of the oscilloscope and set the oscilloscope controls for channel 2 as follows: Sensitivity: 0.5 or 1 V/div Coupling: DC

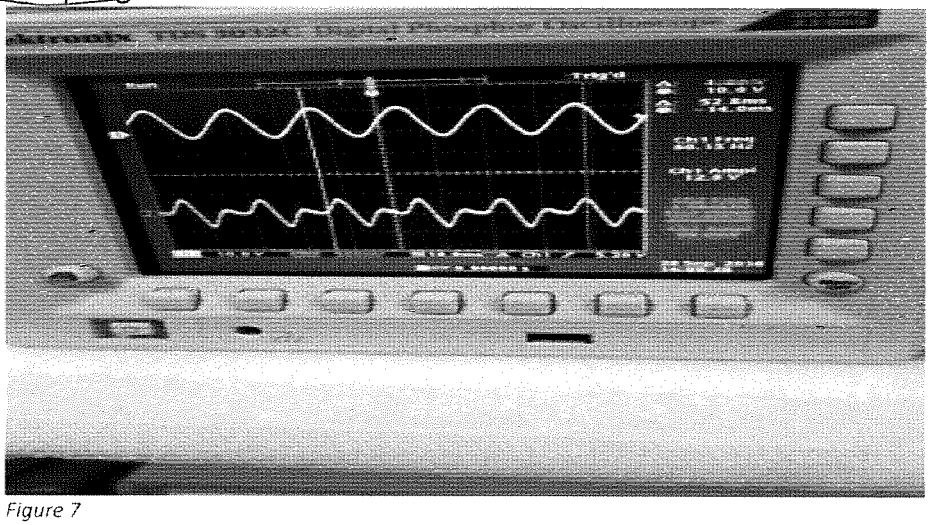


Figure 7

6- After plugging the medium sized RF Probe into the Probe Unit and inserting the sample of DPPH into the coil of the probe, I turn on the Probe Unit by flipping the On/Off switch to the up (I) position and turned the Amplitude knob on the Probe Unit to a medium setting, the Frequency control knob on the Probe Unit to produce an output of approximately 50 MHz.

7- I put U_{mod} to about the 4th position above zero and Increased U_0 from zero to a medium value, so the Helmholtz coil current is about 1.0 A, the oscilloscope traces showed:

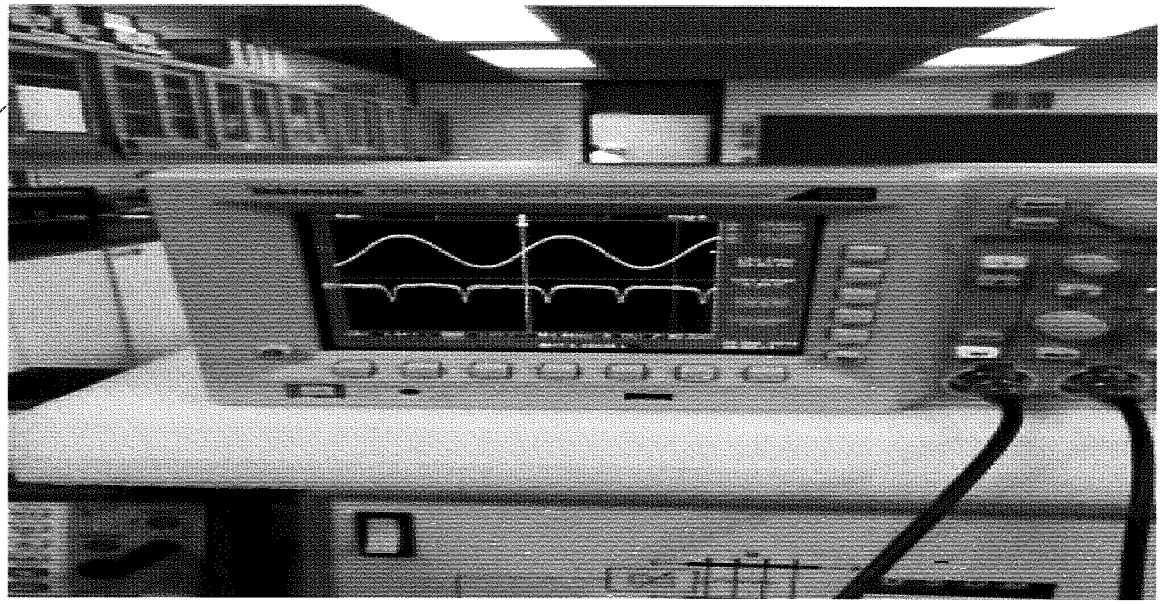


Figure 8

In the figure8, the channel 1 trace displays the current to the Helmholtz coils, which is proportional to the magnetic field produced by the coils. The channel 2 trace displays the envelope of the voltage across the RF oscillator, with the pulses showing the points of resonance absorption.

8- As before, two resonance pulses can be observed since the magnetic field passes through the correct value twice each cycle. By adjusting the Phase Shifter, the two peaks can be brought into coincidence. The resulting trace was:

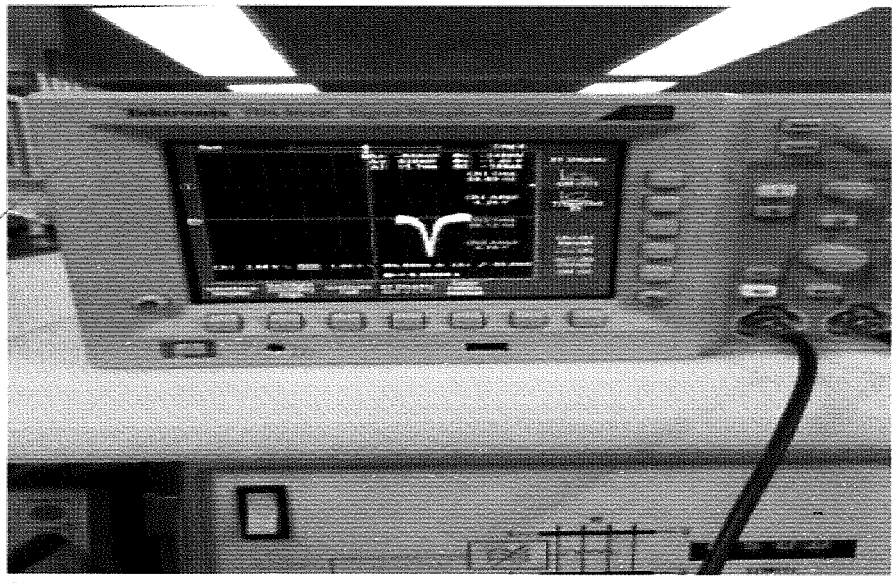


Figure 9

9- To refine the adjustment of the DC current until the resonance pulses occur when the AC component of the current to the Helmholtz coils is zero. I did this step by: 1) Make the channel 1 of the oscilloscope (the trace showing the current to the Helmholtz coils) is in the AC coupled mode. 2) from the oscilloscope controls, I grounded the input to channel 1, zero the trace, and then ungrounded the input.

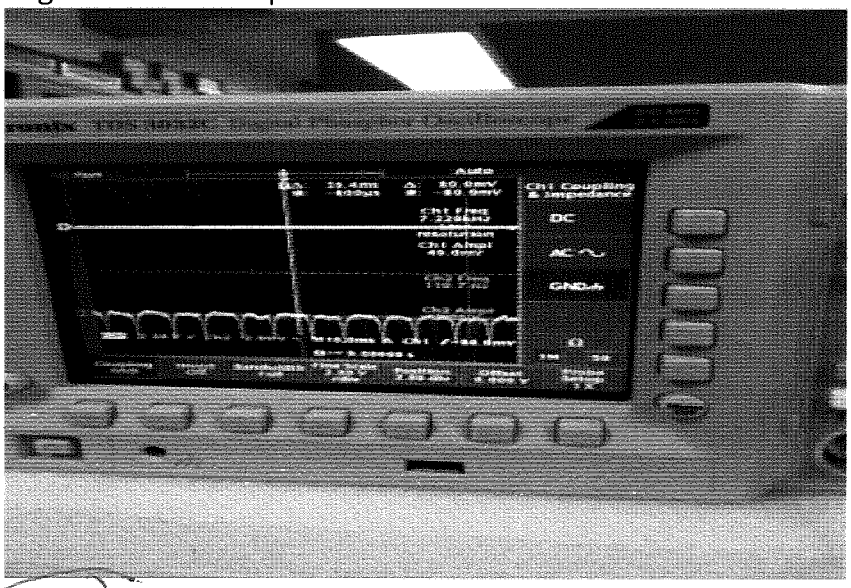


Figure 10

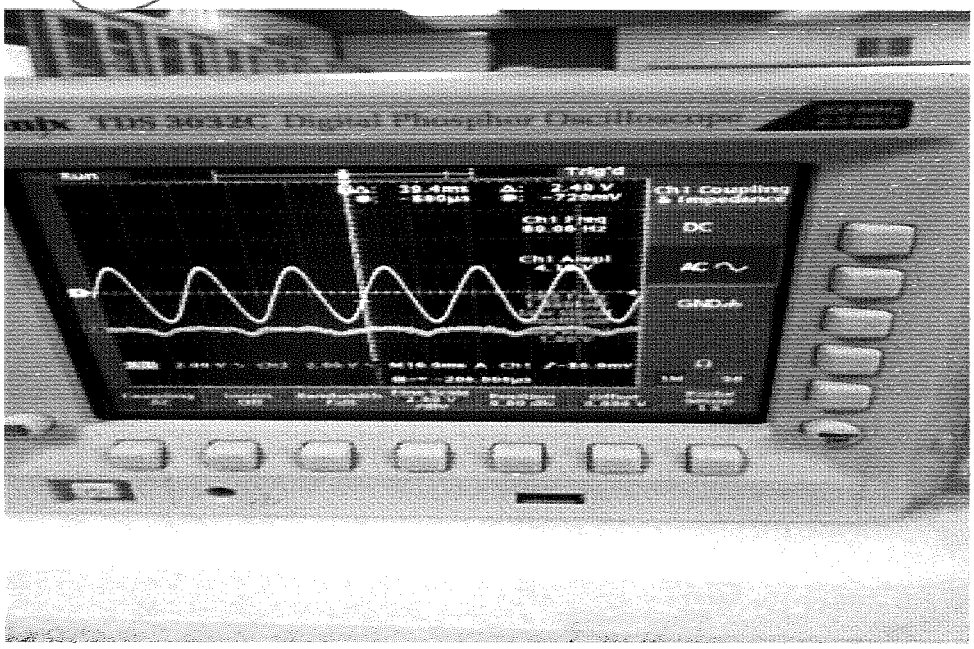


Figure 11

3) I adjusted the DC current and noticed how the resonance pulses move closer together or farther apart. By adjusting the DC current and the phase shifter, until the pulses occur just when the AC current to the Helmholtz coils is zero.

10-With these adjustments, the oscilloscope traces were:

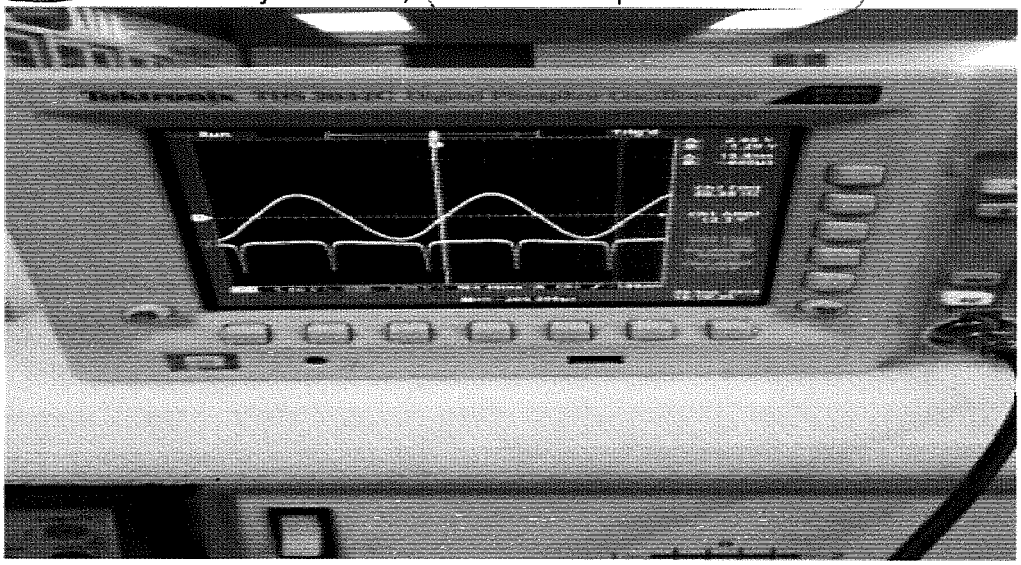


Figure 12

III- EXPERIMENTAL DATA AND DISCUSSION:

- Determining the resonance magnetic field B_0:

In Table, the current through the series-connected Helmholtz coils I_0 in the case of resonance is listed as a function of the frequency v of the alternating high frequency field and the values calculated for the magnetic field are compiled.

v/MHz	I (ampere)	plug-in coil	B(millitesla)
15	0.127	big	0.53721
20	0.168	big	0.71064
25	0.206	big	0.87138
30	0.3	big	1.269
35	0.305	medium	1.29015
40	0.326	medium	1.37898
45	0.377	medium	1.59471
50	0.428	medium	1.81044
55	0.463	medium	1.95849
60	0.512	medium	2.16576
80	0.677	small	2.86371
85	0.717	small	3.03291
90	0.76	small	3.2148
95	0.819	small	3.46437
100	0.851	small	3.59973

I calculated The magnetic field B of the Helmholtz coils from the current I through each coil:

$$B = \mu_0 \cdot \left(\frac{4}{5}\right)^{\frac{3}{2}} \cdot \frac{n}{r} \cdot I \text{ with } \mu_0 = 4\pi \cdot 10^{-7} \frac{Vs}{Am}$$

(n: number of turns per coil, r: radius of the coils) With n = 320 and r = 6.8 cm, B=4.23 mT. I /A

-Determining the half-width δB_0:

The half-width read from the oscilloscope, 1.5 cm corresponding to:

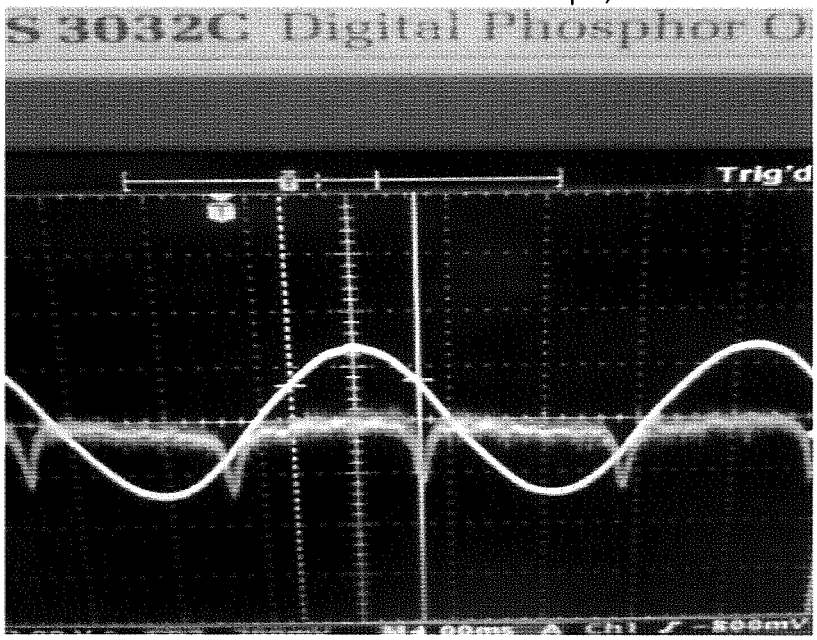


Figure 12

δU= 1.5 cm. 0.2(v/cm) =0.3 V (1.5 cm is the distance between the two vertical lines in figure 12)

Calibration of the full modulation voltage U_{mod}:

U_{mod}= 10cm . 0.5 (v/cm)= 5V

(10cm is the Extend the resonance signal in the X direction exactly over the total width of the screen) which corresponds to I_{mod} = 0.282 A (RMS of AC).

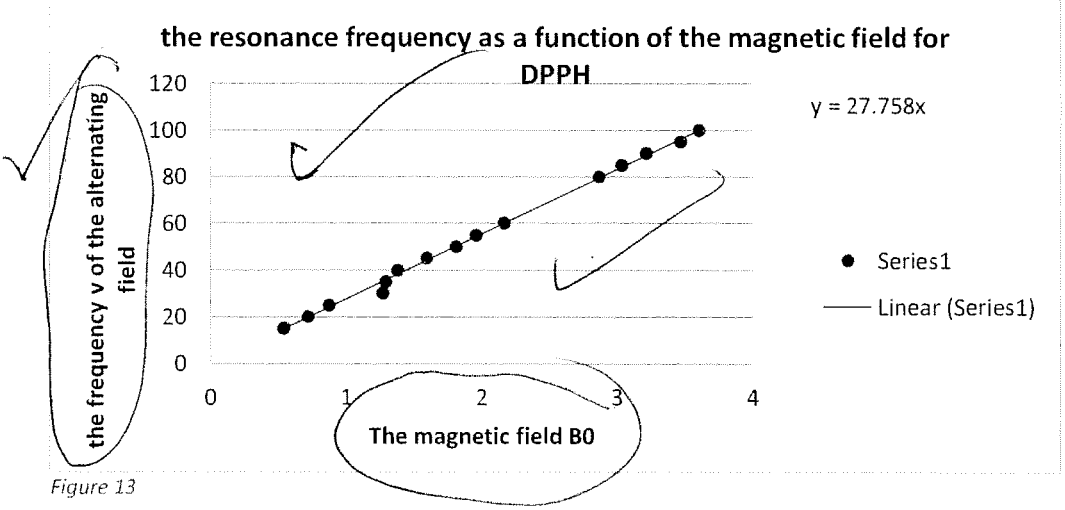


Figure 13

The last plot is the resonance frequency as a function of the magnetic field for DPPH. It shows a plot of the measured values. The slope of the straight line through the origin drawn in the plot is

$\frac{\nu}{B_0} = 27.758 \frac{MHz}{mT}$

From this the g-factor follows : $g = \frac{h.\nu}{u_0.B_0} = \frac{6.625\ 10\text{^}(-34)\ Ws}{9.273\ 10\text{^}(-24)\ Am)} . 27.758\ \frac{MHz}{mT} = 1.983$

Value quoted in the literature: g(DPPH) = 2.0036. The percentage error is:

$$\% \text{ Error} = \left| \frac{\text{Theoretical Value} - \text{Experimental Value}}{\text{Theoretical Value}} \right| \text{X } 100$$

%Error=100. [(2.0036-1.983)/ 2.0036] =1.028%

Peak-to-peak Amplitude $2\sqrt{2}$ of RMS

$\delta I = (\delta U / U_{mod}) * I_{Mod} = (0.3\ V / 5\ V) * 0.282\ A * 2\sqrt{2} = 0.0478\ A$

Then

$\delta B = (4.23\ mT) * \delta I / A = 4.23\ mT * 0.0478\ A/A = 0.202\ mT$

Value quoted in the literature: $\delta B0$ (DPPH) = 0.15-0.81 mT

IV.CONCLUSION:

Quantum theory tells us: electrons have certain properties such as spin. Any type of angular momentum, including spin, can be coupled with a magnetic field. Such a coupling, along with microwave spectroscopy, can be used to study specific attributes of certain types of materials. The particular sample I looked at was DPPH, due to its strong microwave absorption and its almost free spin electrons. The main objective of this lab is to determine the g-factor of DPPH. The slope of the frequency versus applied magnetic field [Figure 13] was used to calculate the g-factor of DPPH. More data should be taken with realigning the Helmholtz coils to improve the uncertainty in the g-factor. Electron Spin Resonance is a very useful tool to do in any molecular analysis.

Samples of PP Presentations of Experiments

Nuclear Magnetic Resonance

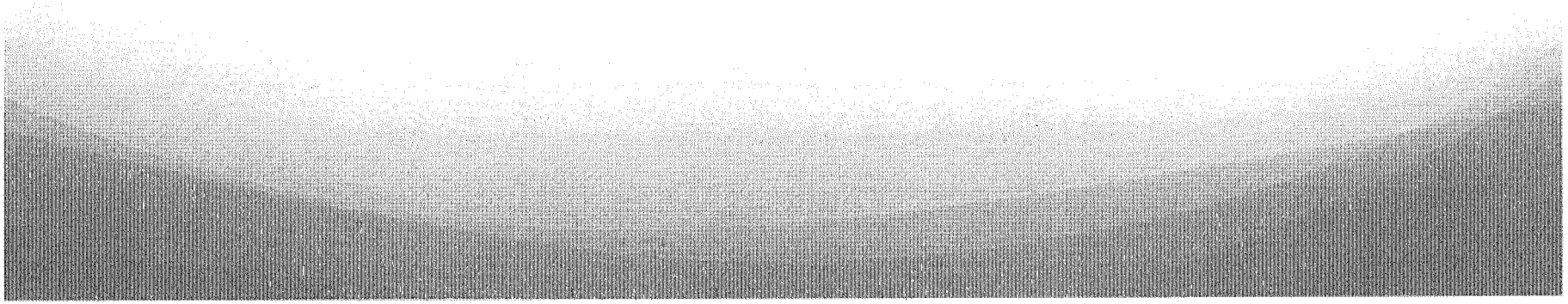
21/25

Abdulkarim Osama Hariri, 201228600

Supervisor: Akhtar A. Naqvi

Out line

- **Introduction**: Uses and achivments
- **Theory**: nuclear spin, relaxation time
- **Experiment**: T1 and T2
- **Results**: glycerin
- **Conclusion**



Introduction

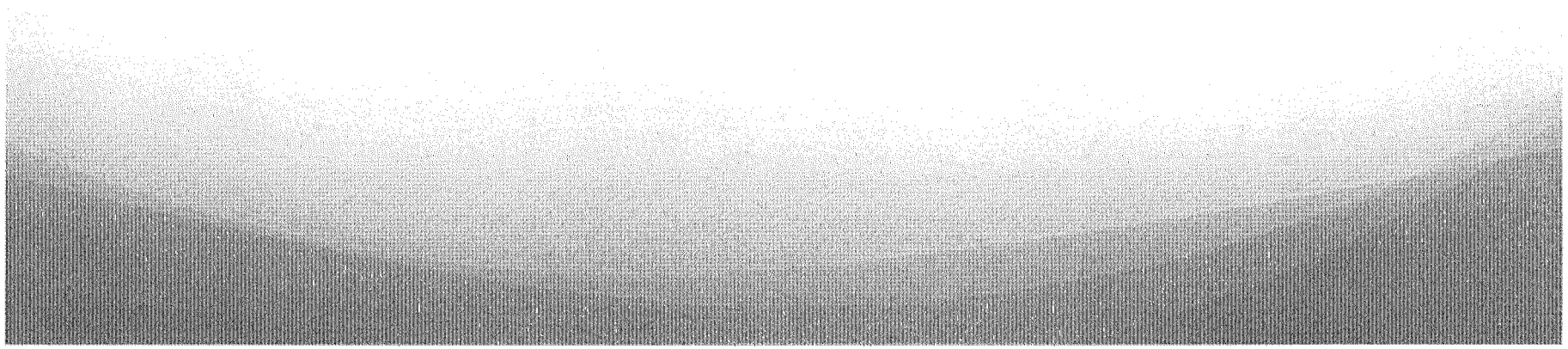
Use of NMR:

1) identifying new compounds

2) distinguishing between isotopes

3)dynamical features of chemical systems

4) medicine (MRI)



Nobel prize

- **Otto Stern, USA:** Nobel Prize in Physics 1943, "for his contribution to the development of molecular ray method and his discovery of the magnetic moment of the proton"
- **Isidor I. Rabi, USA:** Nobel Prize in Physics 1944, "for his resonance method for recording the magnetic properties of atomic nuclei"
- **Felix Bloch, USA and Edward M. Purcell, USA:** Nobel Prize in Physics 1952, "for their discovery of new methods for nuclear magnetic precision measurements and discoveries in connection therewith"
- **Richard R. Ernst, Switzerland:** Nobel Prize in Chemistry 1991, "for his contributions to the development of the methodology of high resolution nuclear magnetic resonance (NMR) spectroscopy
- **Kurt Wüthrich, Switzerland:** Nobel Prize in Chemistry 2002, "for his development of nuclear magnetic resonance spectroscopy for determining the three-dimensional structure of biological macromolecules in solution"
- **Paul C. Lauterbur, USA and Peter Mansfield, United Kingdom:** Nobel Prize in Physiology or Medicine 2003, "for their discoveries concerning magnetic resonance imaging"

Theory

- Nuclear spin and nuclear magnetic moment

$$\vec{u} = \gamma \vec{s}.$$

- Interaction with magnetic field

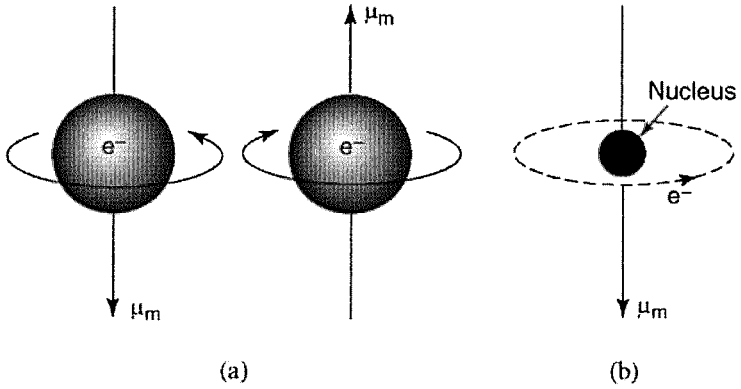
$$E = -\vec{u} \cdot \vec{B}_o.$$

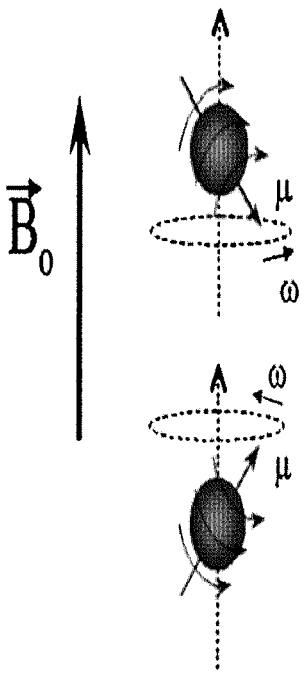
$$E = (\gamma m_z \hbar B_o) = u_z B_o$$

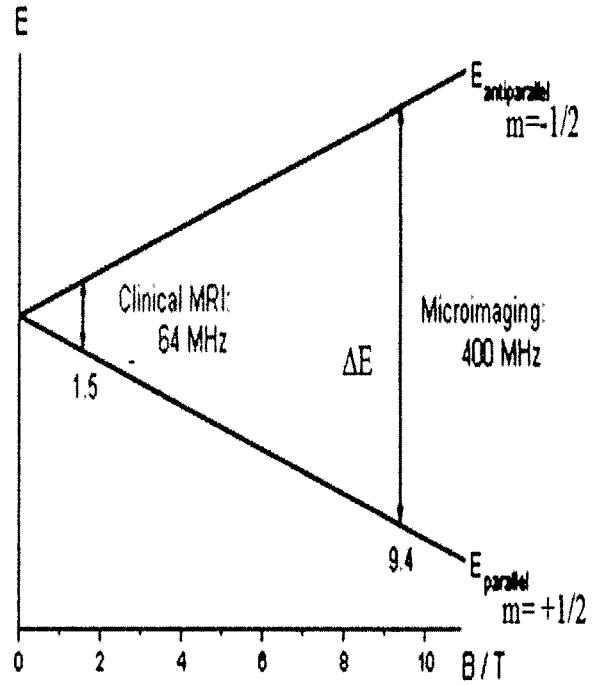
$$\Delta E = \gamma \hbar B_o$$

$$\Delta E = \hbar\omega = \hbar 2\pi f = hf$$

$$f = (\gamma B_0)/2\pi$$

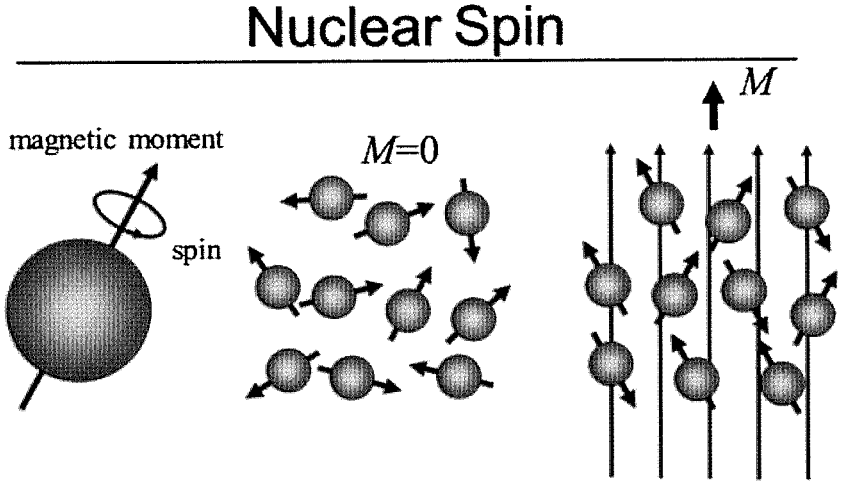






Theory

- Spin-lattice relaxation time : T_1 : component of M ll to B



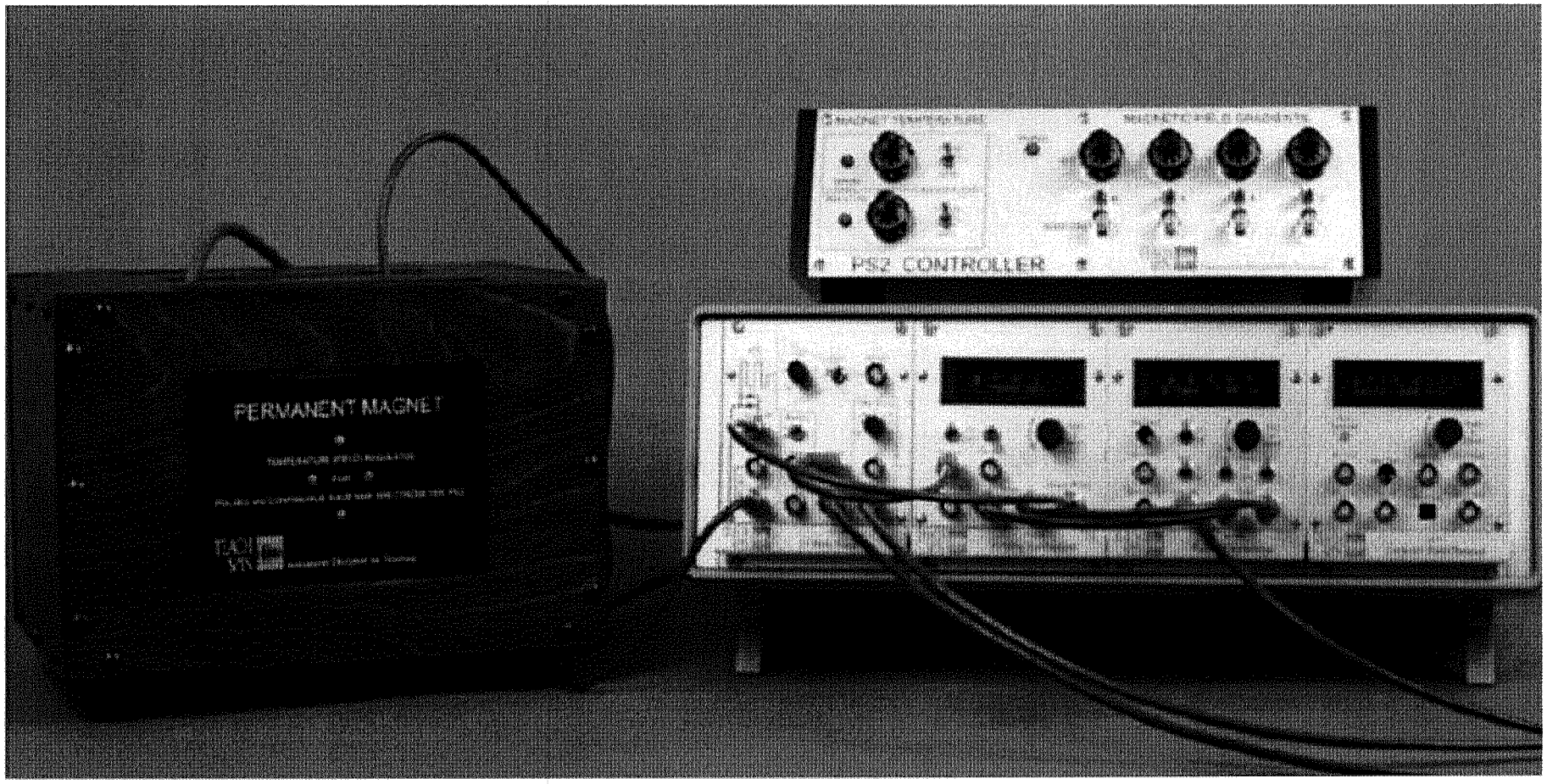
If a nucleus has an unpaired proton it will have spin and it will have a net magnetic moment or field

- Spin-spin relaxation time : T_2

Component of M $\perp$ B

Experiment

- A) Experimental set up



Experiment

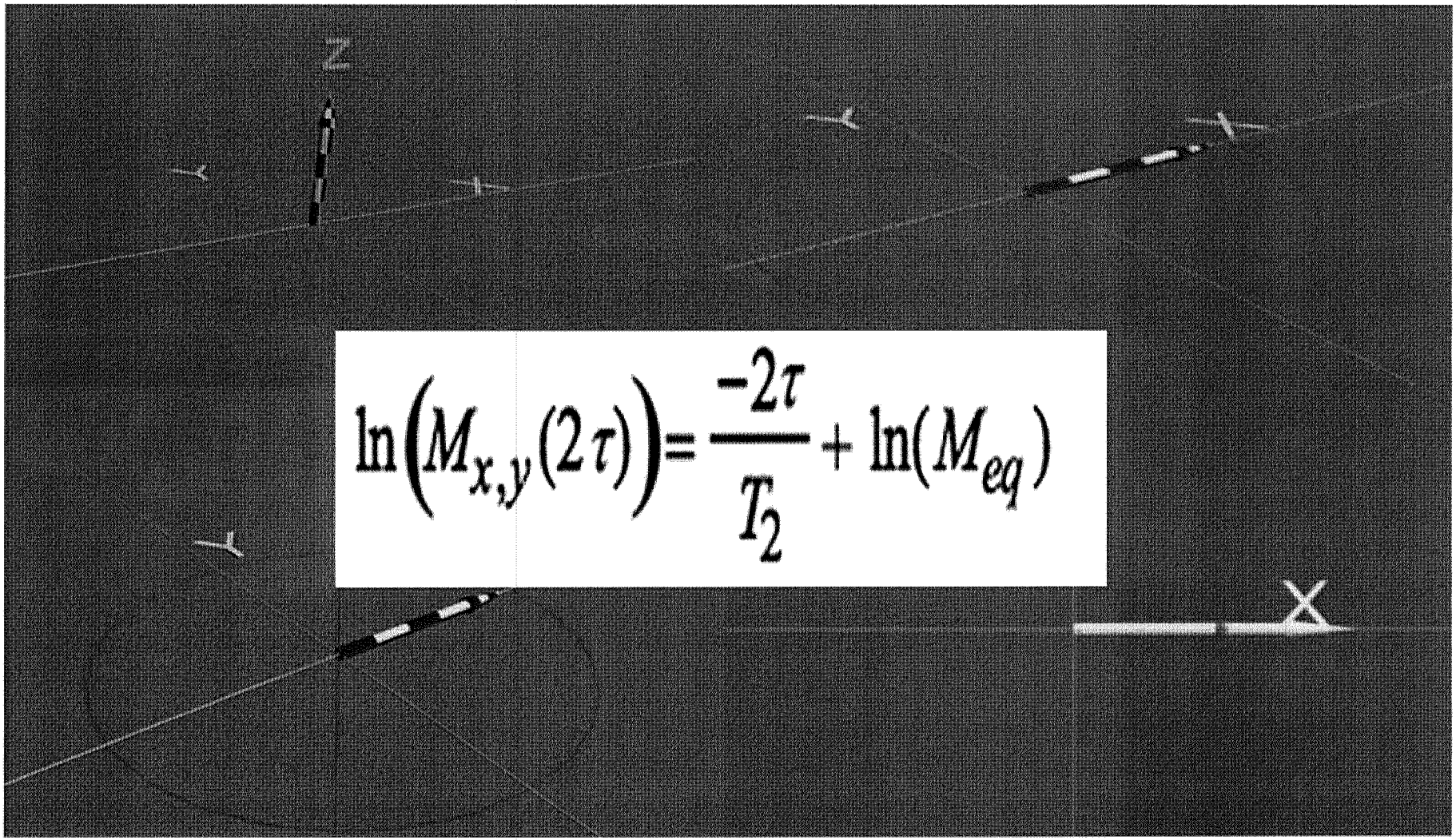
- B) Method for measuring T_1

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

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

Experiment

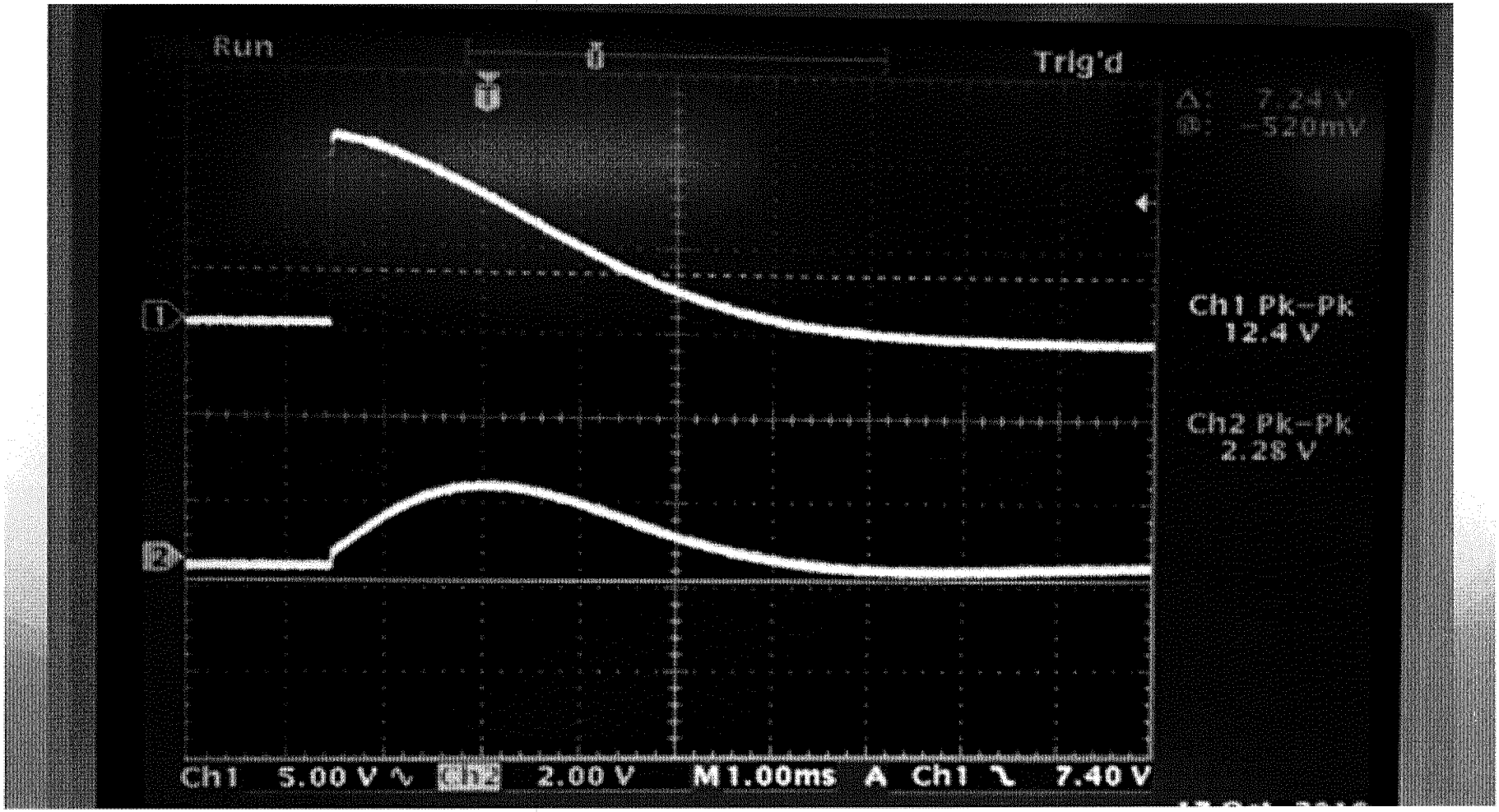
- C) Method for measuring T_2 90^0--- τ ---180^0 --- τ --- echo (2τ)



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

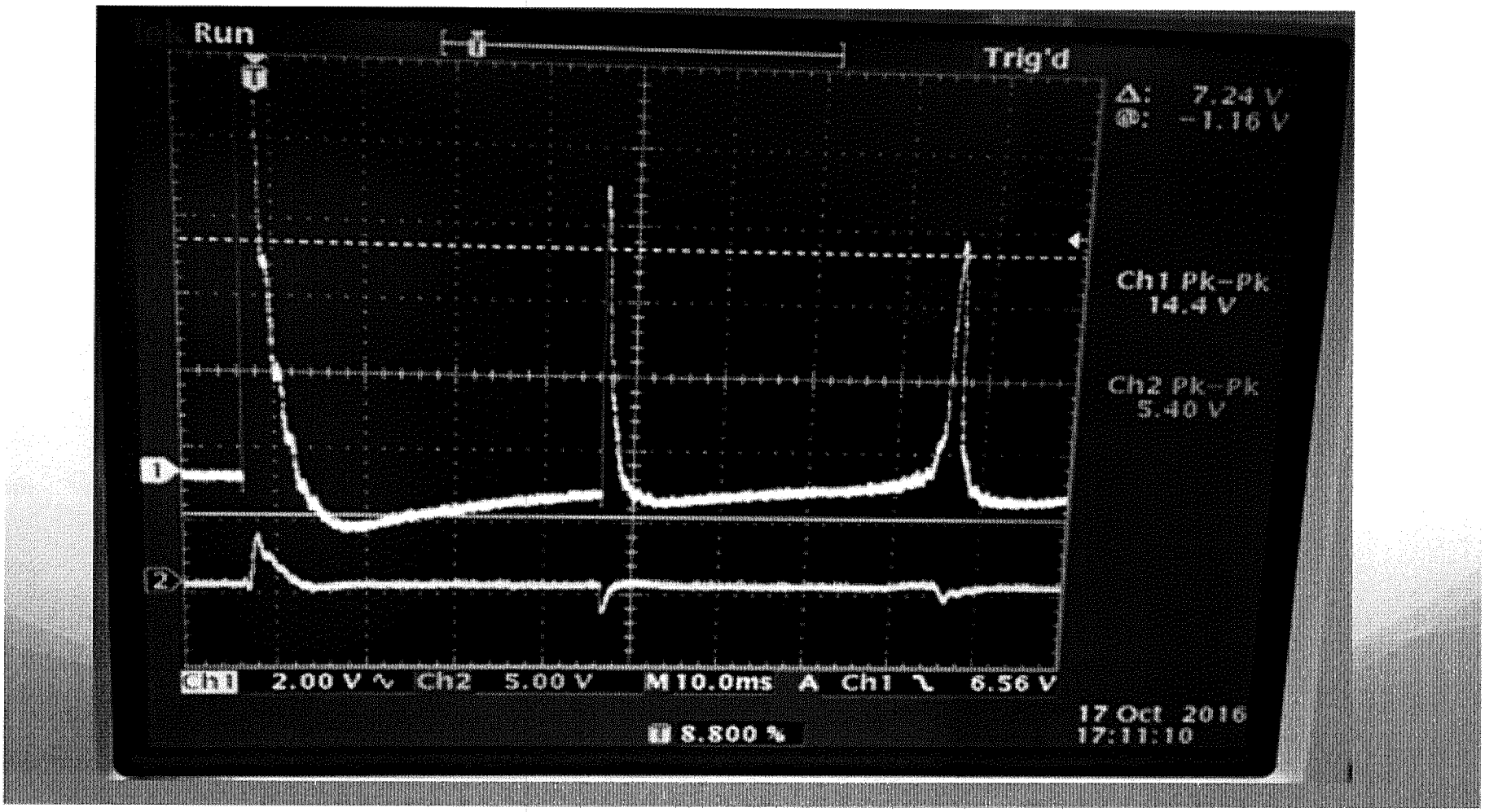
Results

- T_1 signal (M(t)) for glycerin



Results

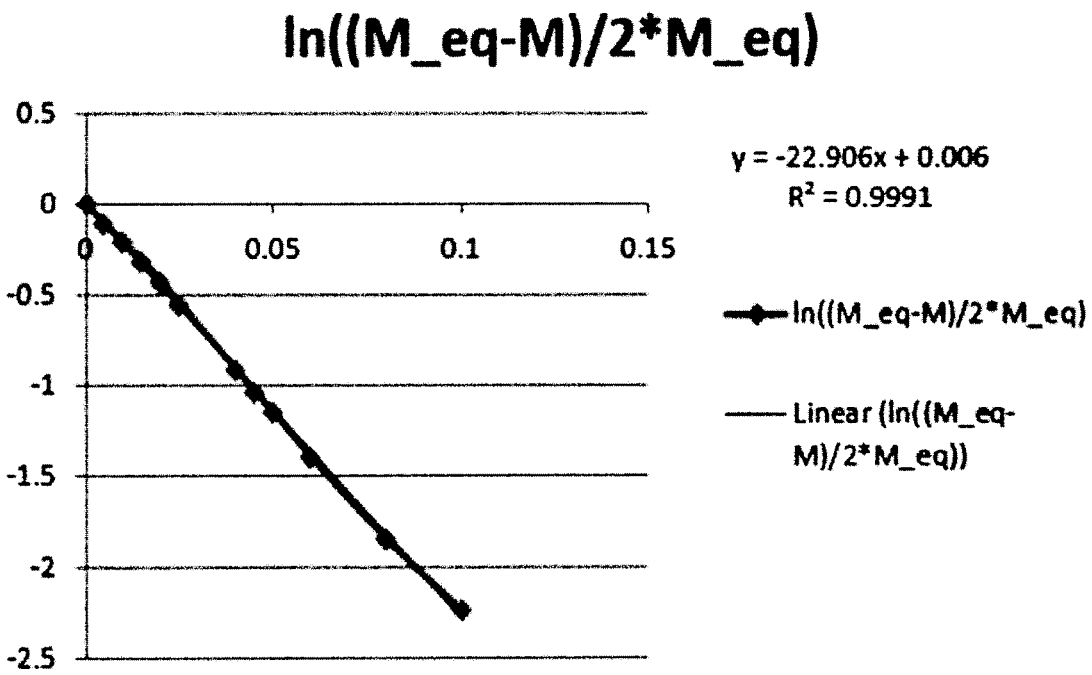
- T_2 signal (M(t)) for glycerin



Results

- T_1 results

tau	M(t) two	M_eq	ln((M_eq-M)/2*M_eq)
0	-12.6	12.7	-0.003944778
0.005	-9.95	12.7	-0.114589322
0.01	-7.8	12.7	-0.214324288
0.015	-5.8	12.7	-0.316978442
0.02	-3.8	12.7	-0.431388793
0.025	-1.95	12.7	-0.550308839
0.04	2.55	12.7	-0.917275469
0.045	3.73	12.7	-1.040863498
0.05	4.7	12.7	-1.155307632
0.06	6.44	12.7	-1.400568989

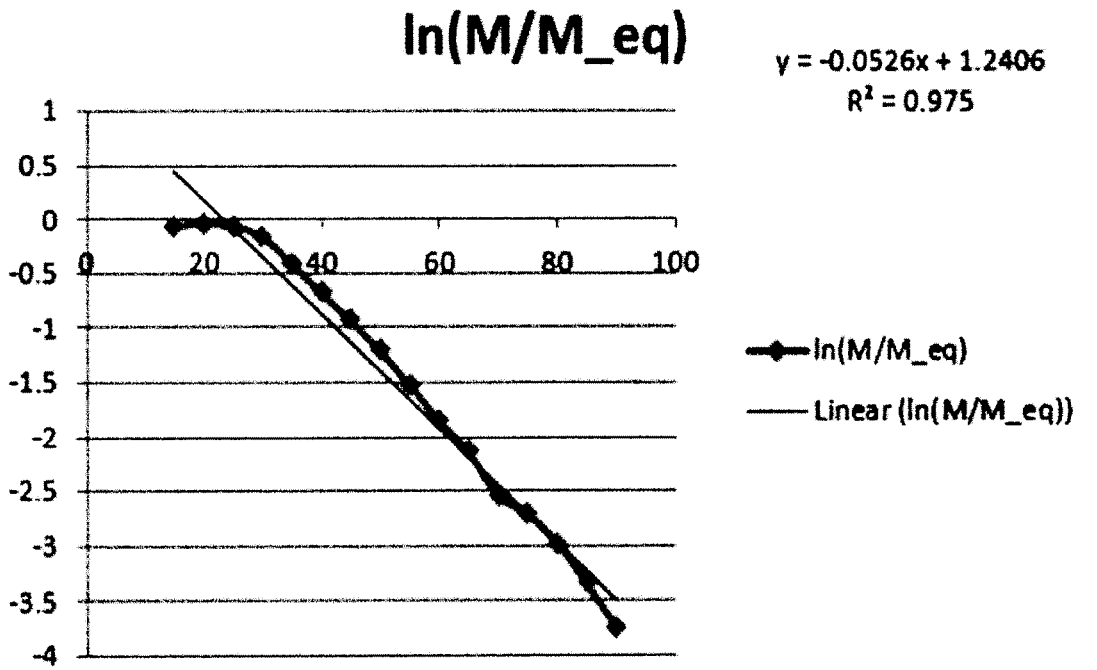


T_1 = 0.04366 s , error = 7 %

Results

- T_2 results

tau	M(t)	M_eq	ln(M/M_eq)
15	12	12.7	-0.0566953
20	12.3	12.7	-0.0320027
25	12	12.7	-0.0566953
30	10.9	12.7	-0.1528392
35	8.5	12.7	-0.4015358
40	6.5	12.7	-0.6697998
45	5	12.7	-0.9321641
50	3.8	12.7	-1.2066009
55	2.8	12.7	-1.5119826
60	2	12.7	-1.8484548
65	1.5	12.7	-2.1361369
70	1	12.7	-2.541602
75	0.85	12.7	-2.7041209
80	0.65	12.7	-2.9723849
85	0.45	12.7	-3.3401097
90	0.3	12.7	-3.7455748

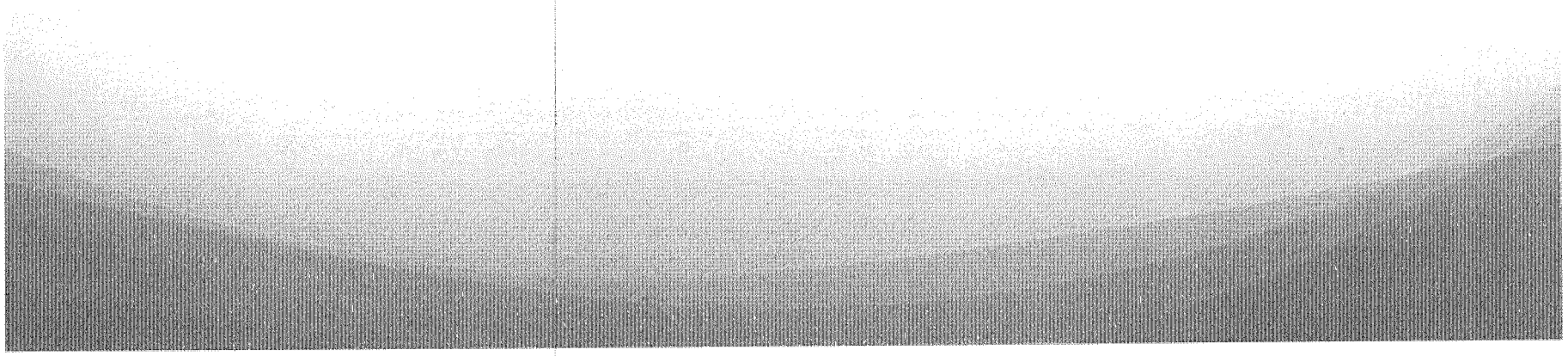


T_2 = 0.01901 s , error = 9%

Results

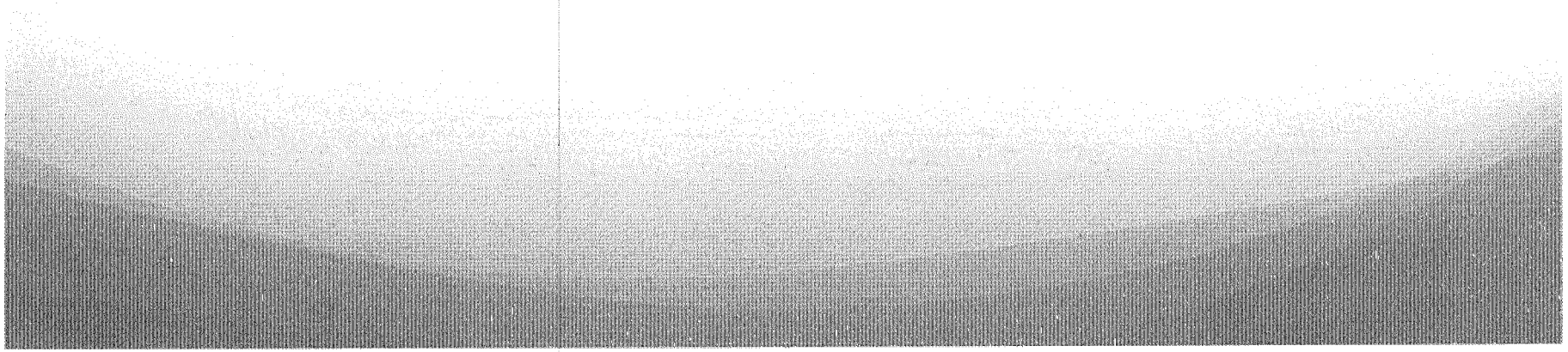
- Confirming the data

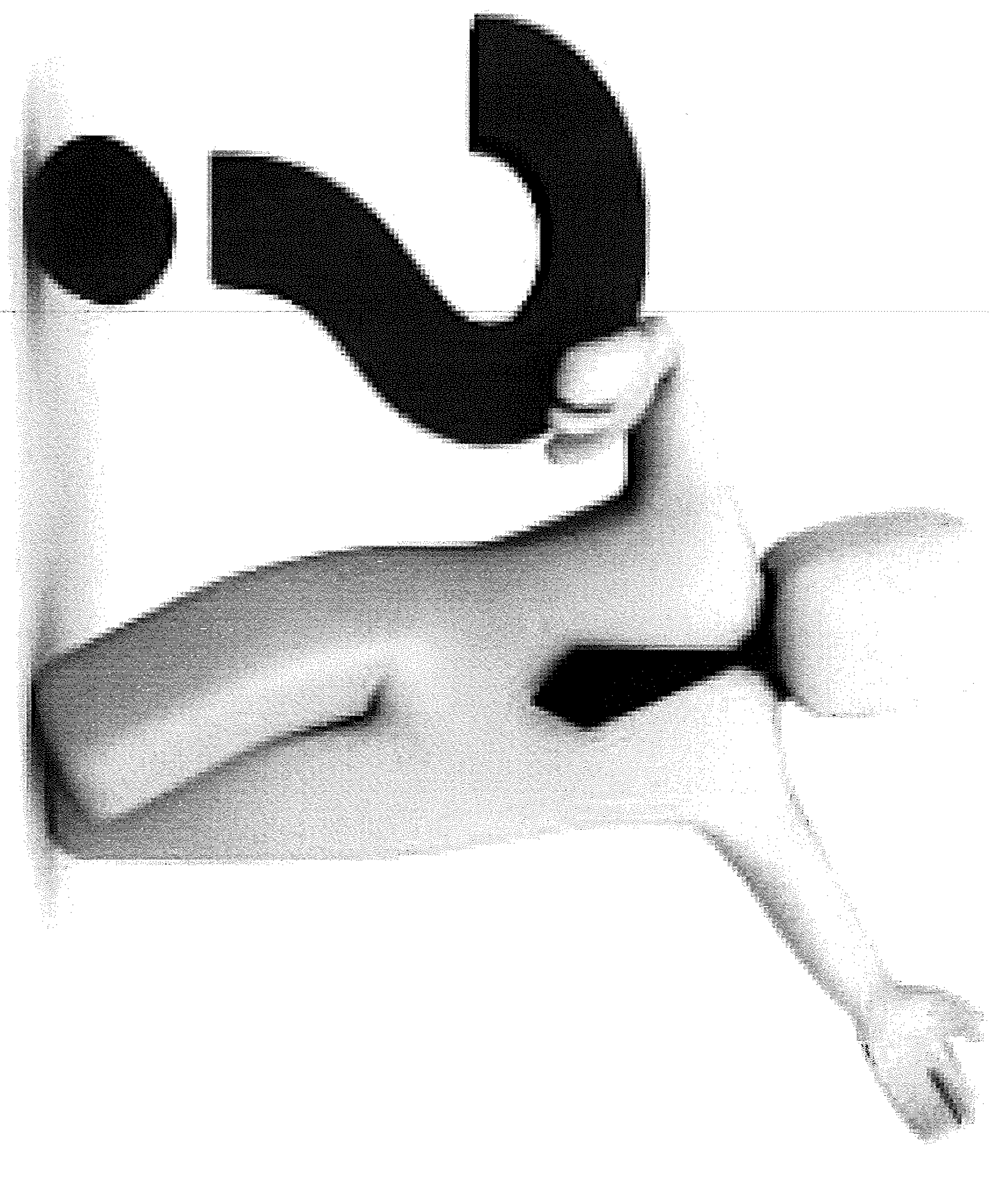
- Sources of error: heating



Conclusion

- NMR is a very helpful technique (used in…)
- Nuclear spin and magnatic moment
- T_1 and T_2

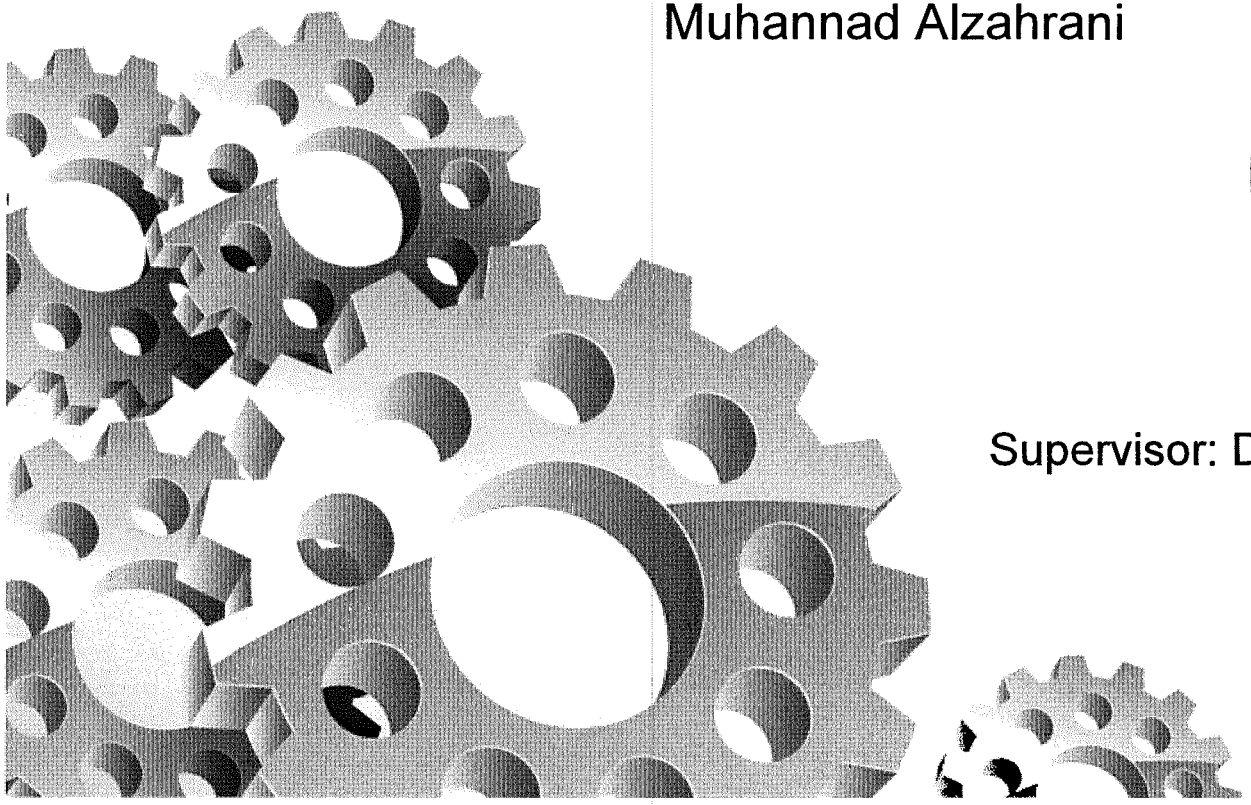




X-ray diffraction

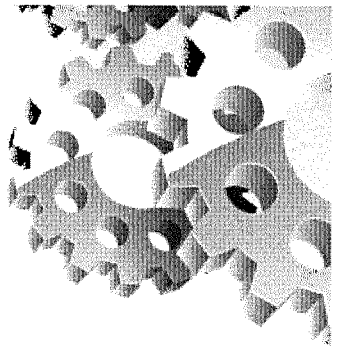
Muhannad Alzahrani

21/25



Supervisor: Dr. Akhtar Naqvi

Presentation Outline



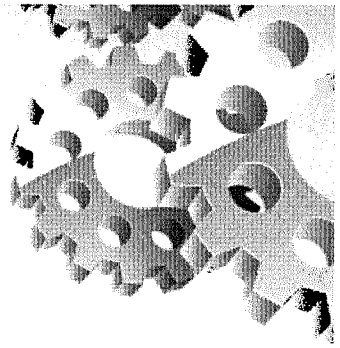
- Introduction
- Theoretical Background
- Experimantal Procedure
- Results and Discussion
- Conclusion

Introduction (1)

- X-ray was first discovered by Wilhelm Rontgen in 1895
- The typical wavelength of of X-ray is 0.01 to 10 nm.
- Mainly use in Physics to to explore the crystalls structure.
- Other uses include medical CT scans and airport security devices.

First X-ray Photo

Introduction (2)



We have done three experiments:

1-Fine structure of characteristic X-ray for molybdenum anode.

2-determination of Plank's constant via Duant-Hunt relation

3- diffraction of X-ray at a monocrystal (Verifying Bragg's relation)

Theoretical Background (1)

- For the first experiment...
- Energy is quantized (QM), and transitions are associated with emission or absorption of energy.
- Fine structure → Splitting lines of transitions.
- K_α and K_β are proved to be line duplets, will be explored by means of X-ray diffraction.
- These transitions obey selection rules
  $|\Delta l| = 1, |\Delta j| = 0, 1$

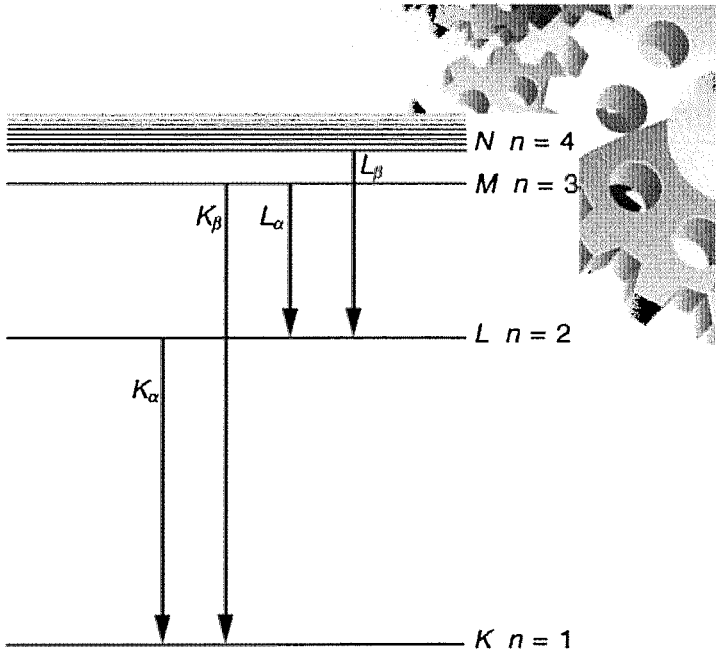
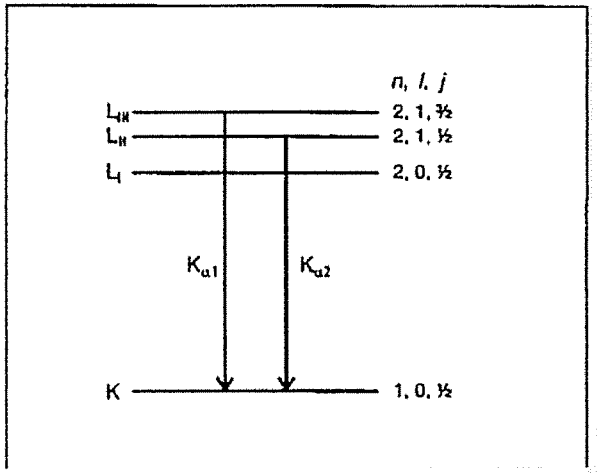
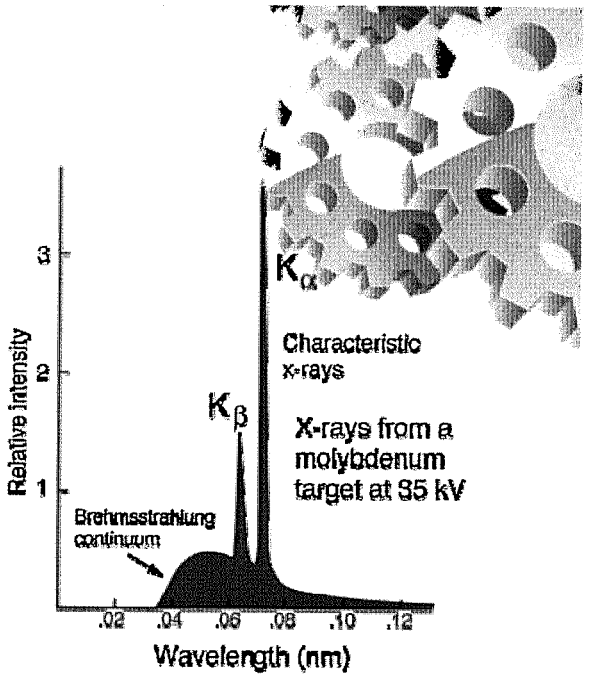


Fig. 1 Diagram of fine structure of the characteristic line K_α



Theoretical Background (2)

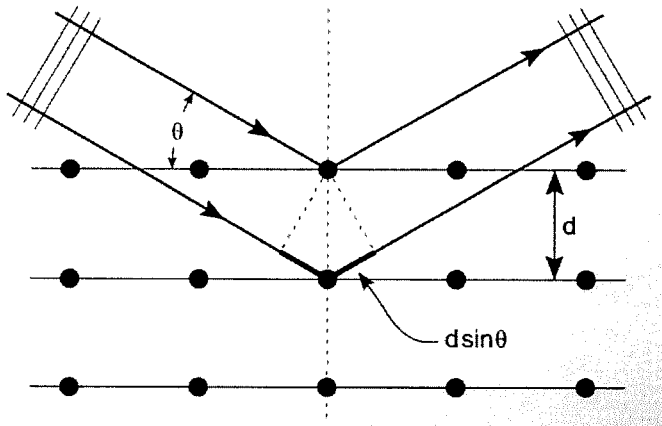
- For the second experiment...
- Duant and Hunt found that at the Brehmsstrhlung continuum in the relative intensity and wavelength curve that $\lambda_{min} \sim 1/U$, the exact relation is $\lambda = (hc/e)(1/U) = A / U$



- For the third experiment...

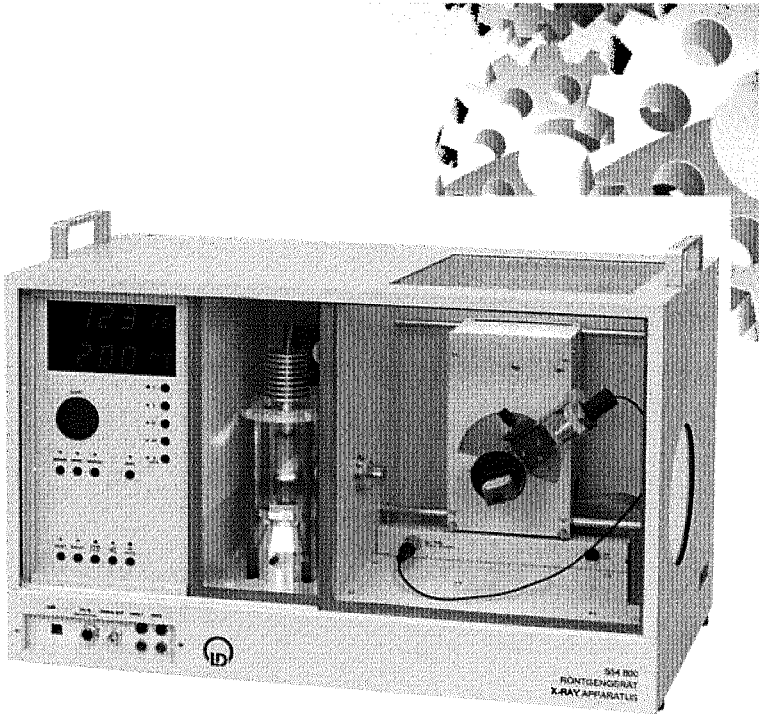
- Crystalls are arrays of lattice elements or parallel lattice planes (Bragg).

- Bragg got the relation $2d \sin(\theta) = n\lambda$ (constractive interference condition)



Experimental Procedure (1)

• All experiments had been carried out by Leybold X-ray diffraction machine.



• The device consists of three parts:
  1- Control Panal: To adjust the different parameters involved
  2- X-ray emmitor.
  3- Experiment room: Containing an X-ray source, the crystal and the detector.

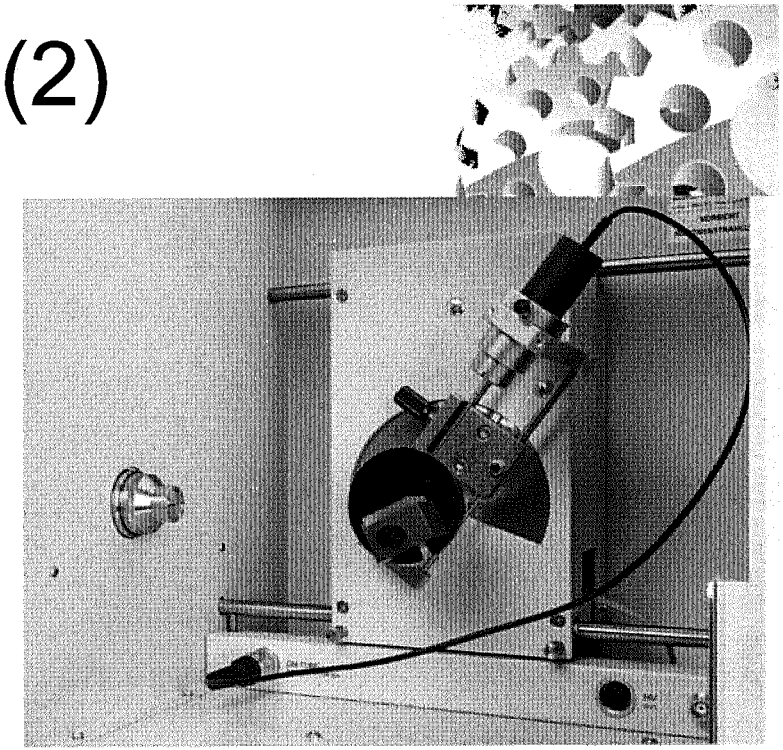
• The last part is a cable attached to a computer to transmitt the data via X-ray apparatus software

Experimental Procedure (2)

- All three experiments have almost the same procedure.
- First, we need to maxmize the counting rate via manipulating the voltage and angles.
- Next, we enter the relevant parameters using the control panal.

- Then, we need to adjust the distances between the X-ray emitter, the crystal and the detector.

- Finally, we have to choose the appropriate plot type in the X-ray apparatus software.



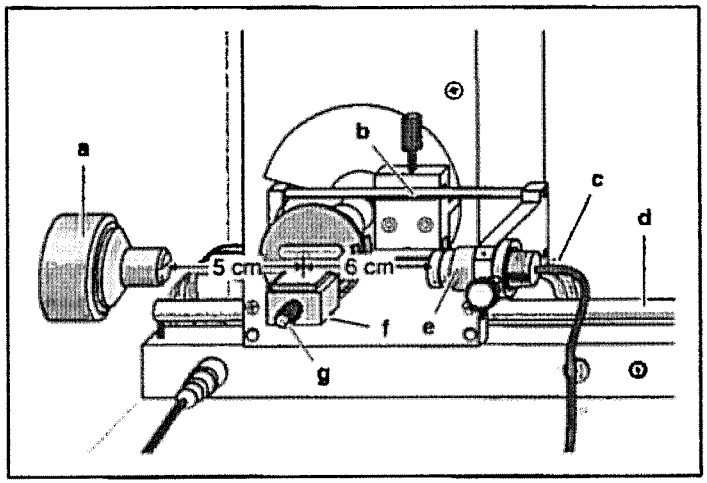
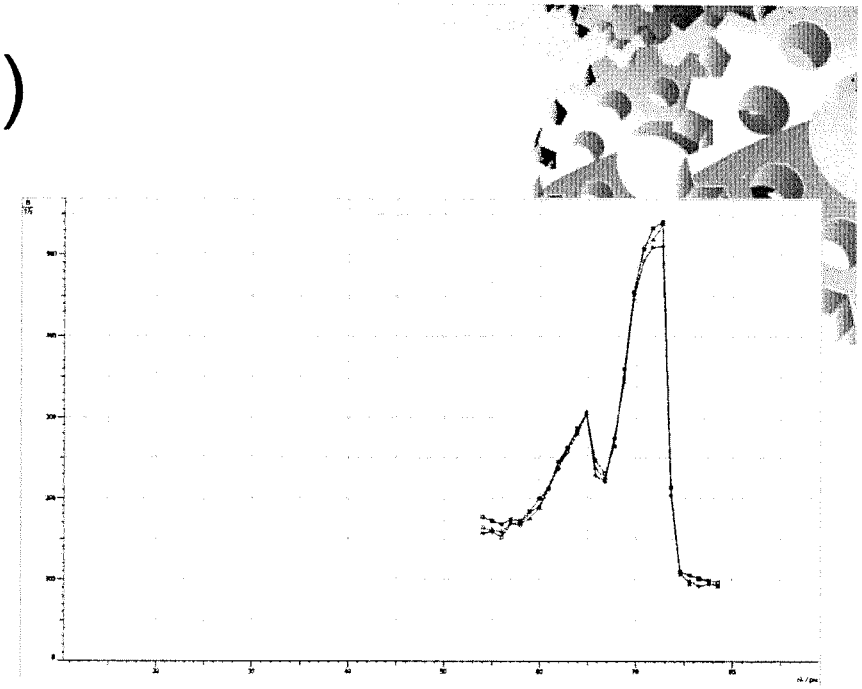


Fig. 4 Experiment setup in Bragg configuration

Results and discussion (1)

- For the first experiment, we have done first order diffraction three consecutive times to find K_α and K_β.
- The first and second peaks corresponds to the K_β and K_α respectivley.
- The obtained values for K_α and K_β respectivley were 73.1 and 65.0, while the literature values are 71.8 and 63.09 (Good agreement)
- Yet, first order diffraction is not enough to resolve $K_{\alpha 1}$ and $K_{\alpha 2}$



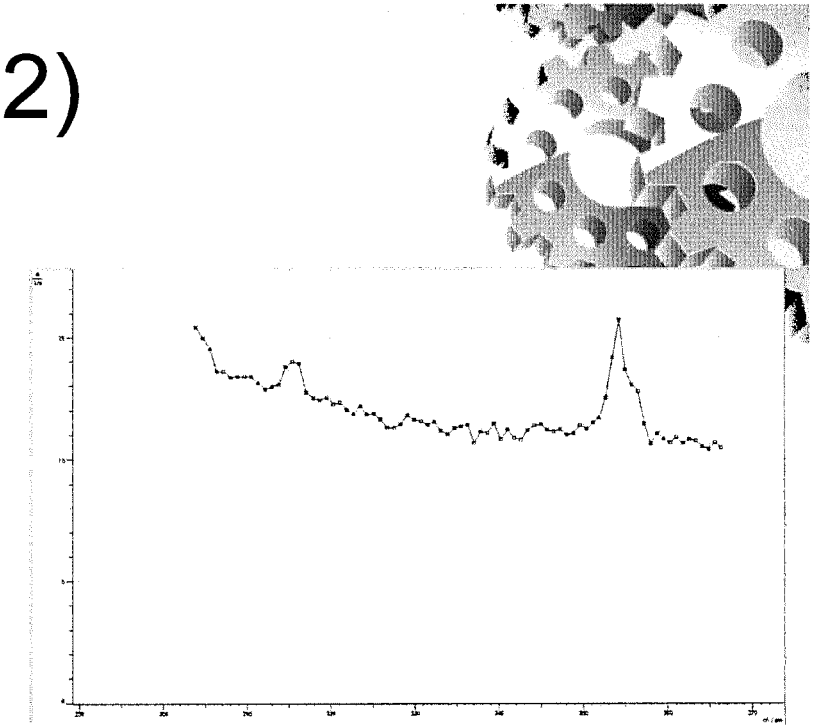
First order diffraction for NACl monocrystall

Results and discussion (2)

- The consecutive peaks represents K_γ, K_β, $K_{\alpha1}$ and $K_{\alpha2}$.

- The obtained for K_γ, K_β, $K_{\alpha1}$ and $K_{\alpha2}$ were 62.2, 63.1, 70.8 and 71.4 (pm), and the literature values were 62.09, 63.26, 70.93 and 71.36 (pm) and the agrrement is good.

- The difference between the curve here and the one in the manual is the upward shift in this case.

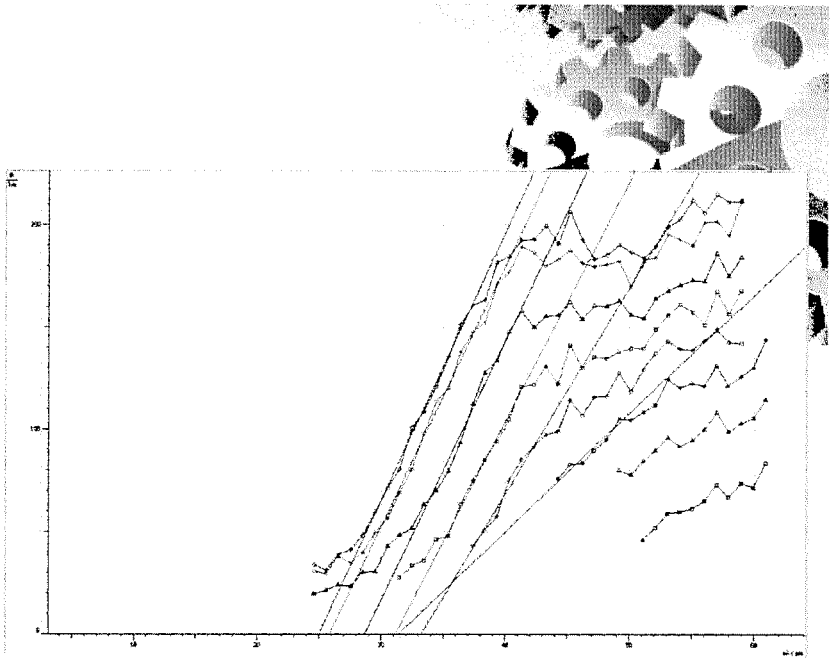


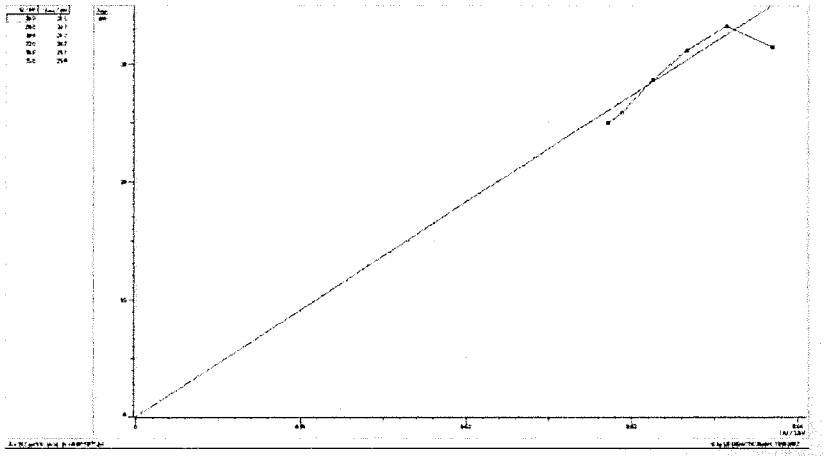
Fifth order diffraction in NACl monocrysall

Results and discussion (3)

- In the third experiment, finding Plank's contant. It is done via performing the experiment for different values of the voltage and finding the corresponding λ_{min} (Upper graph), then plot a regrssion line to find A (Lower graph).

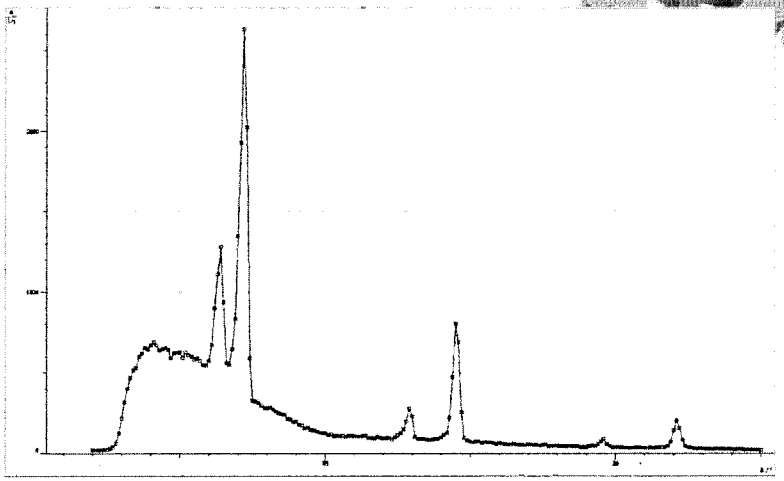
- The obtained value of h was 4.87 *10^-34 J.s, with a considerable deviation from the literature value (6.38*10^-34 J.s), error is 27% (No explanation).

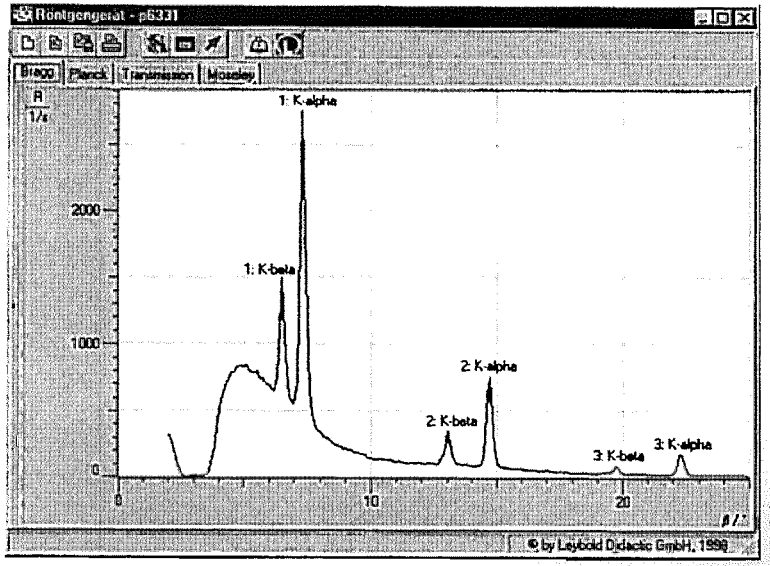




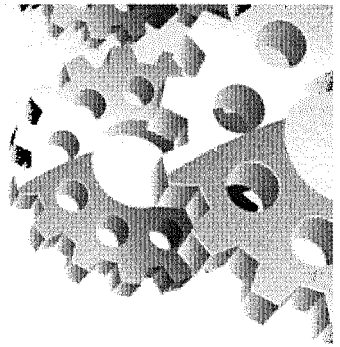
Results and Discussion (4)

- In the third experiment, we verified Bragg's relation.
- The graph is a plot of Internsity of the diffracted beam vs. angle.
- We did not calculate the wavelenghts explicitly, but the plot is almost identical to the one in the manual.



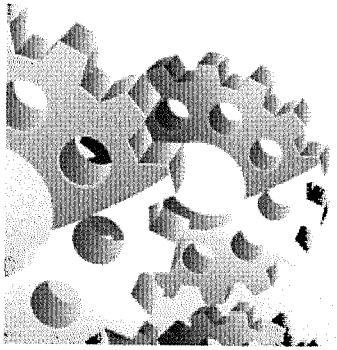


Conclusion



- X-ray diffraction is an indespensible tool in many fields.
- K lines of transition are duplets.
- Bragg's relation is true within experimental sensitivity.
- Counting rate must be high to obtain accurate results

غ



Diode Laser Experiment

Presented by

Hesham Almaleki

21/25

Supervised by

Dr. Akhtar Naqvi

❖ Outline

- **Introduction.**
- **Theory.**
- **Instruments used.**
- **Experiment setup.**
- **Procedure**
- **Conclusion**

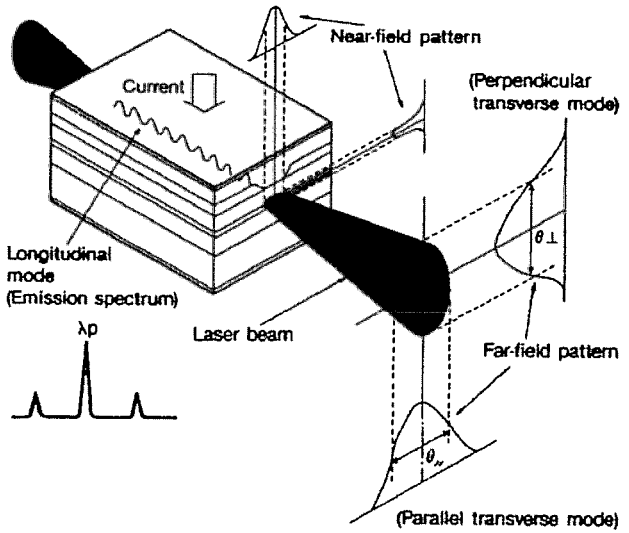
❖ Introduction

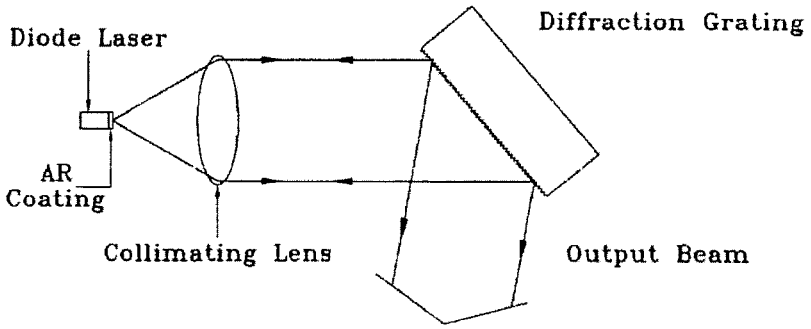
Diode laser is composed of:

- Internal (Bare) DL.

  Laser diodes consist of a p- n diode with an active region where electrons and holes recombine resulting in light emission. Their linewidths are large compared to the linewidths of atomic transitions. In addition they are extremely sensitive to optical feedback

- External Cavity DL (ECDL).





❖ Theory

- Rubidium has two naturally occurring isotopes: ^{85}Rb and ^{87}Rb.
- The nuclear spin quantum number for ^{85}Rb is I = 5/2, whereas for ^{87}Rb, I=3/2.
- Each energy level will occupy a certain state.
- The energy states can be described by:

$$^{2S+1}L'_J$$

where

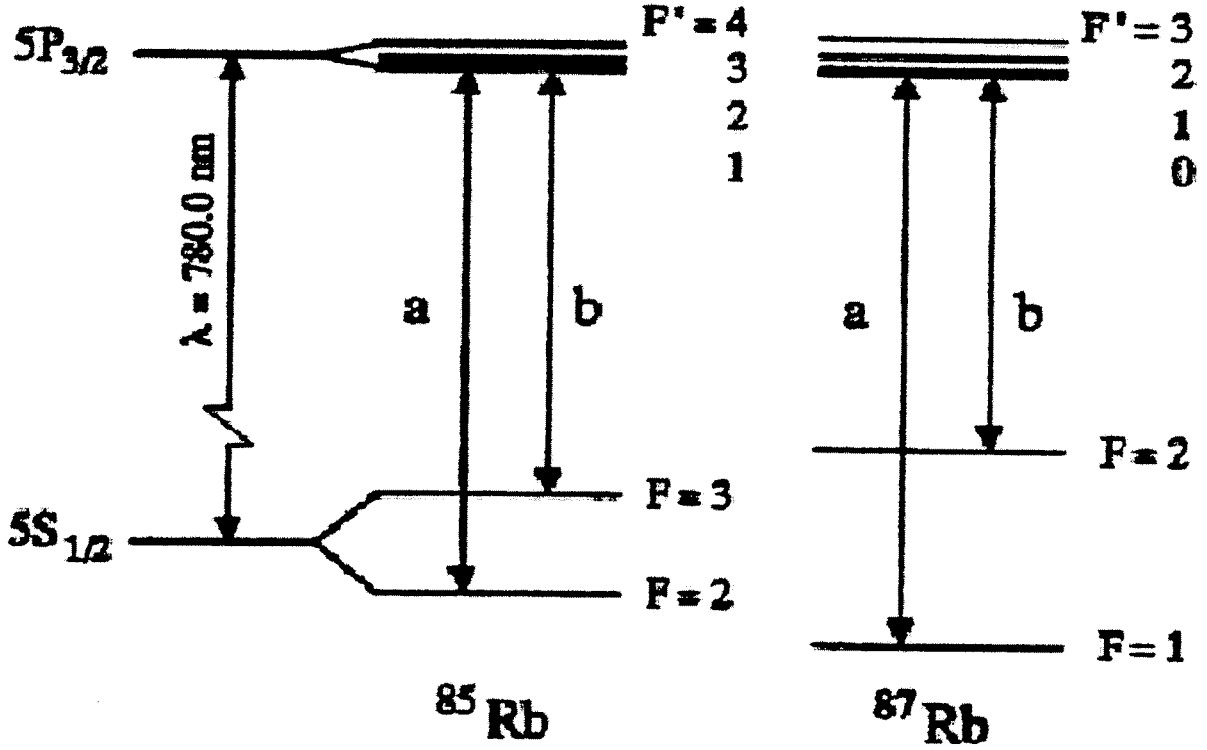
- S: is the spin quantum number.

- L': is the angular momentum quantum number (S, P, D, ..., for orbital angular momentum quantum number L = 0,1,2).

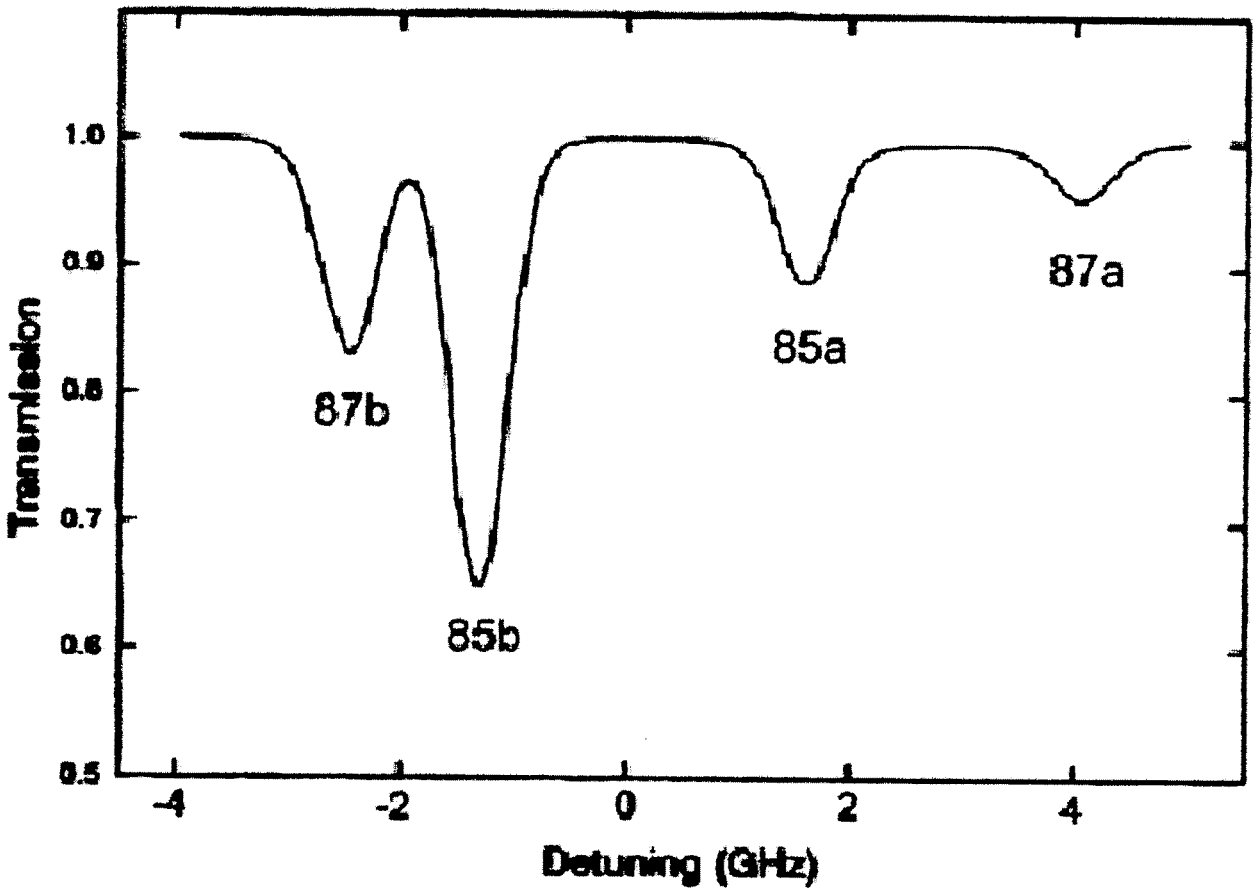
- J = L + S is the total angular momentum quantum number.

- For the ground state of rubidium, S = 1/2 and L = 0, giving J = 1/2 and the ground state, $^2S_{1/2}$.

- For the first excited state we have S = 1/2, and L = 1, giving J = 1/2 or J= 3/2, so there are two excited states $^{1/2}$ P and $^{3/2}$ P.



- The absorption spectrum for a rubidium vapor cell, with the different lines shown.



❖ Instruments used

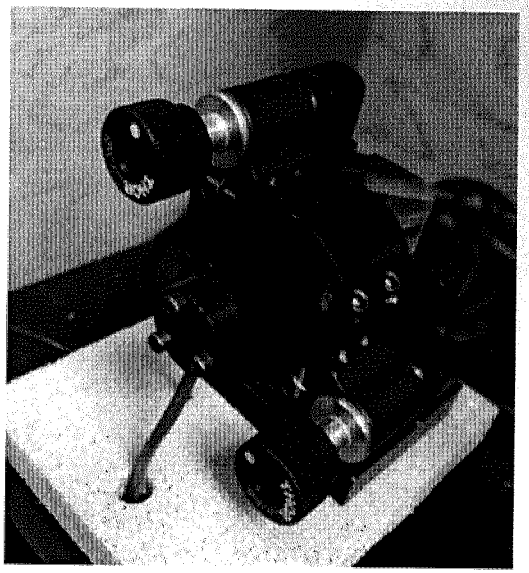
- **Diode laser.**

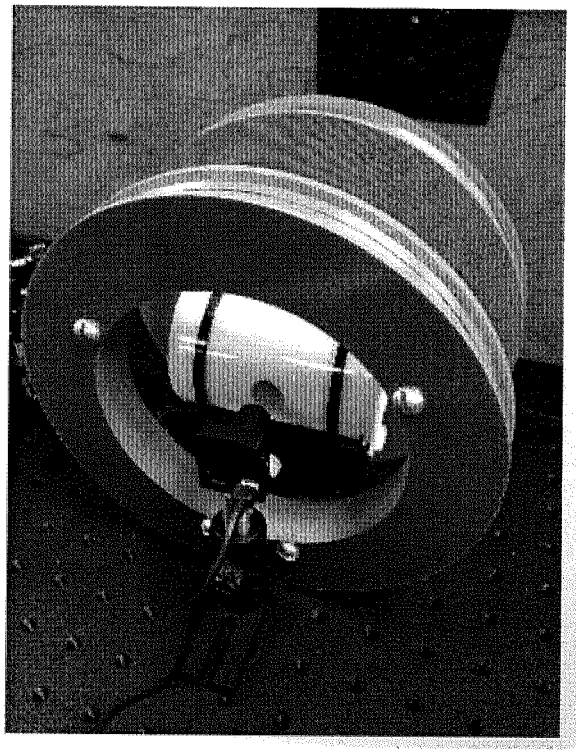
- **The Absorption Cell Assembly.**

  The absorption cell assembly consists on an outer glass cylinder, an insulation layer, a heater assembly, a thermocouple to monitor the temperature and the gas filled Rb cell itself.

- **The Magnetic Field Coils.**

  The magnetic field coils are a Helmholtz pair which produces a uniform field at the Rubidium cell.

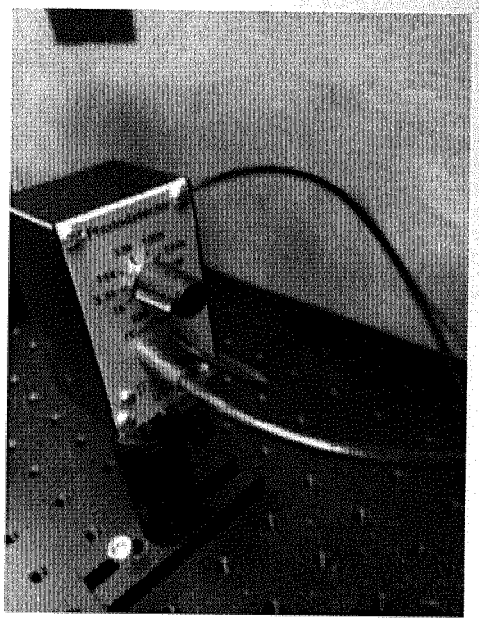




❖ Instruments used

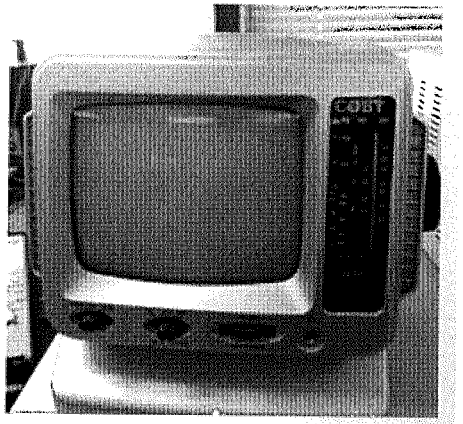
- **The Photodiode Detectors.**

  The apparatus is supplied with a couple of photodiode detectors. A switch on the back of the detector allows you to change the gain setting from 10 M_ to 333 _ in ten steps. We can send the detector signal directly to an oscilloscope or to the DETECTOR MODULE of the Controller.



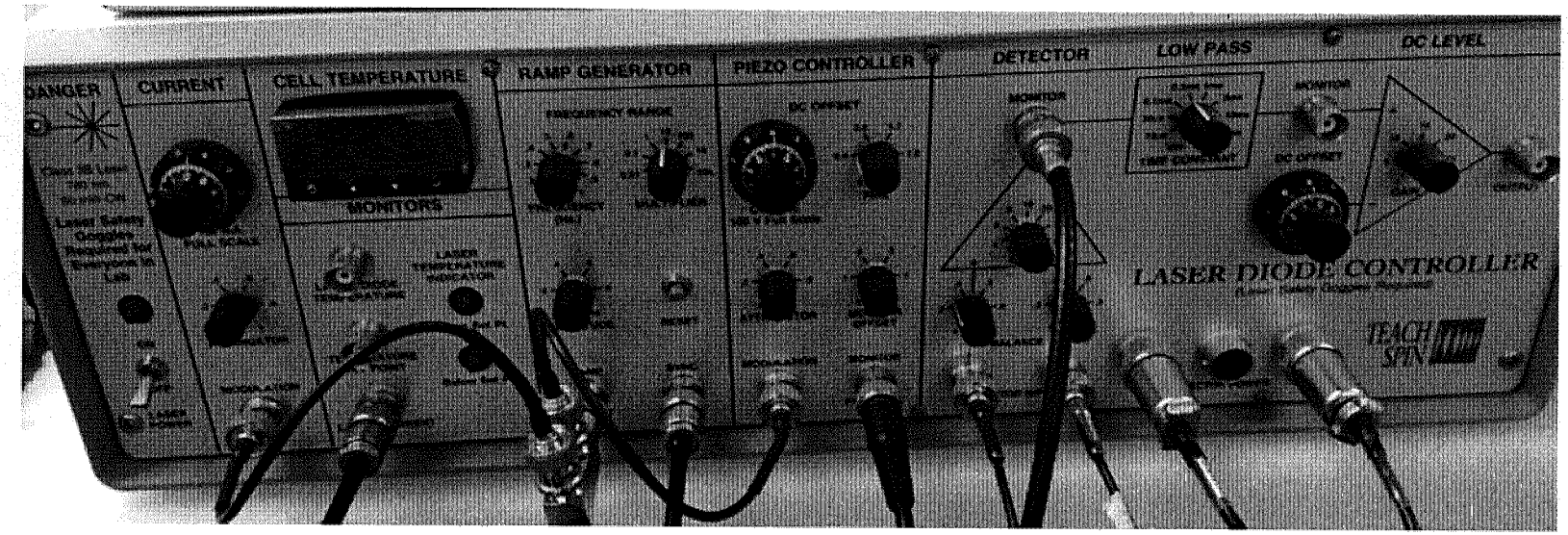
- **A couple of lenses.**
- **An oscilloscope.**
- **TV connected to a camera.**
- **ND filter.**
- **The Magnetic Field Coils.**

  The magnetic field coils are a Helmholtz pair which produces a uniform field at the Rubidium cell.



❖ Instruments used

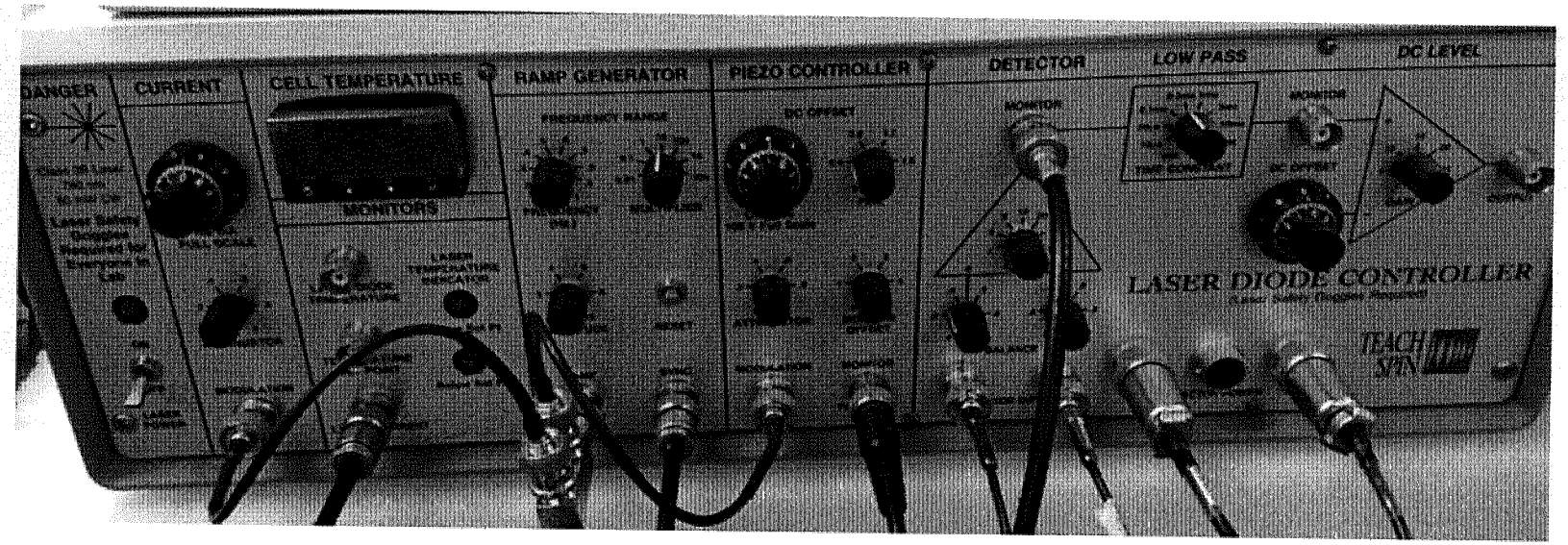
- **The Controller.**



- **DETECTOR/LOW PASS/DC LEVEL:** This module provides power for three detectors and offers two detector inputs and a series of Monitor options. You can look at either detector or a combined signal.
- **PIEZO CONTROLLER:** This controls the piezo modulation, which determines the way the angle of the grating is changed and thus the change or "sweep" of the laser frequency.

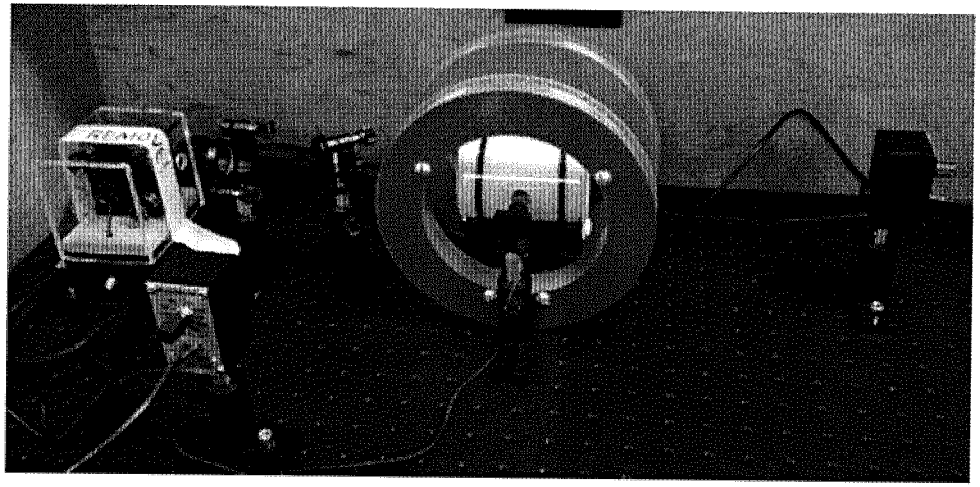
❖ Instruments used

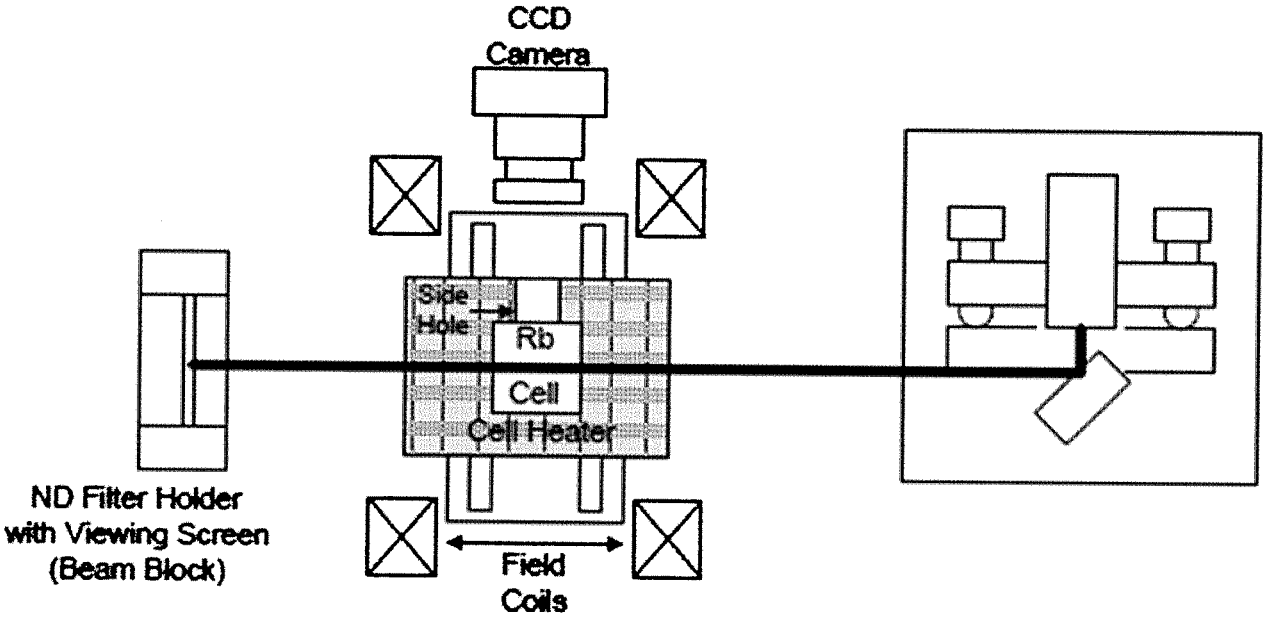
- **The Controller.**

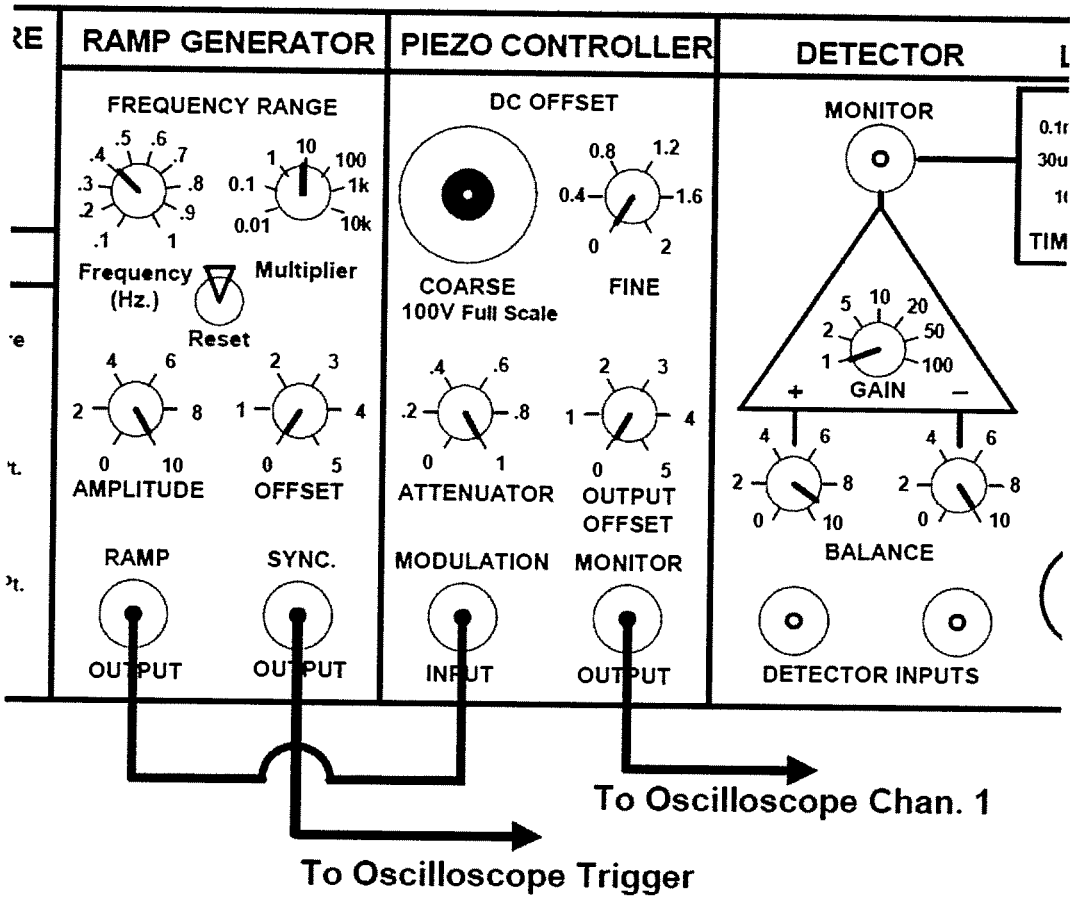


- **RAMP GENERATOR:** This provides a bipolar variable amplitude and frequency triangle wave.
- **CELL TEMPERATURE:** The cell temperature is both set and monitored through keys on the LED display.
- **CURRENT**: The current module controls the current to the laser.

❖ Experiment setup







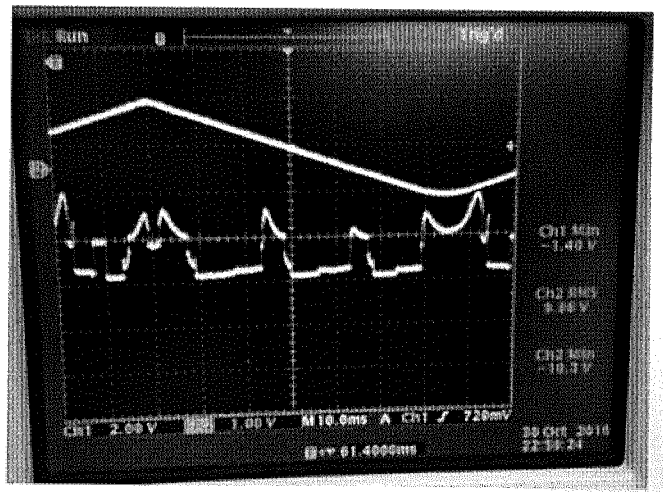
The connection between the oscilloscope and the controller.

❖ Procedure

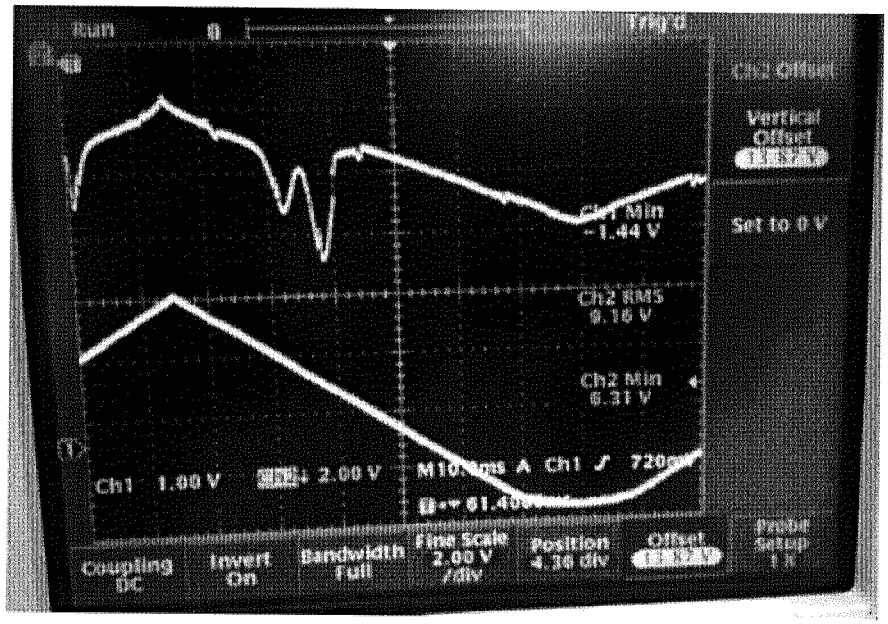
- Set the cell temperature to be 45 degrees.
- You have to wait for the cell to reach this temperature.
- Set the Laser diode voltage to be 2.719 V.
- Turn the piezo OUTPUT OFFSET knob to zero.
- Set the ramp generator frequency to about 10 Hz.
- Turn the piezo ATTENUATOR knob to one (1).
- Set the ramp generator AMPLITUDE knob to ten (10).
- Use the DC OFFSET knob of piezo controller to produce a large-amplitude triangle wave that is not clipped at the top or bottom.
- Put the Photodiode Detector in place to intercept the laser beam coming through the Rb cell. Assemble the glass neutral density filter in a fixed mirror holder and place it in a post holder.
- Place the attenuator between the laser and the Rb cell (not between the cell and
- photodiode).

Upper trace (Channel 1) shows piezo monitor signal.

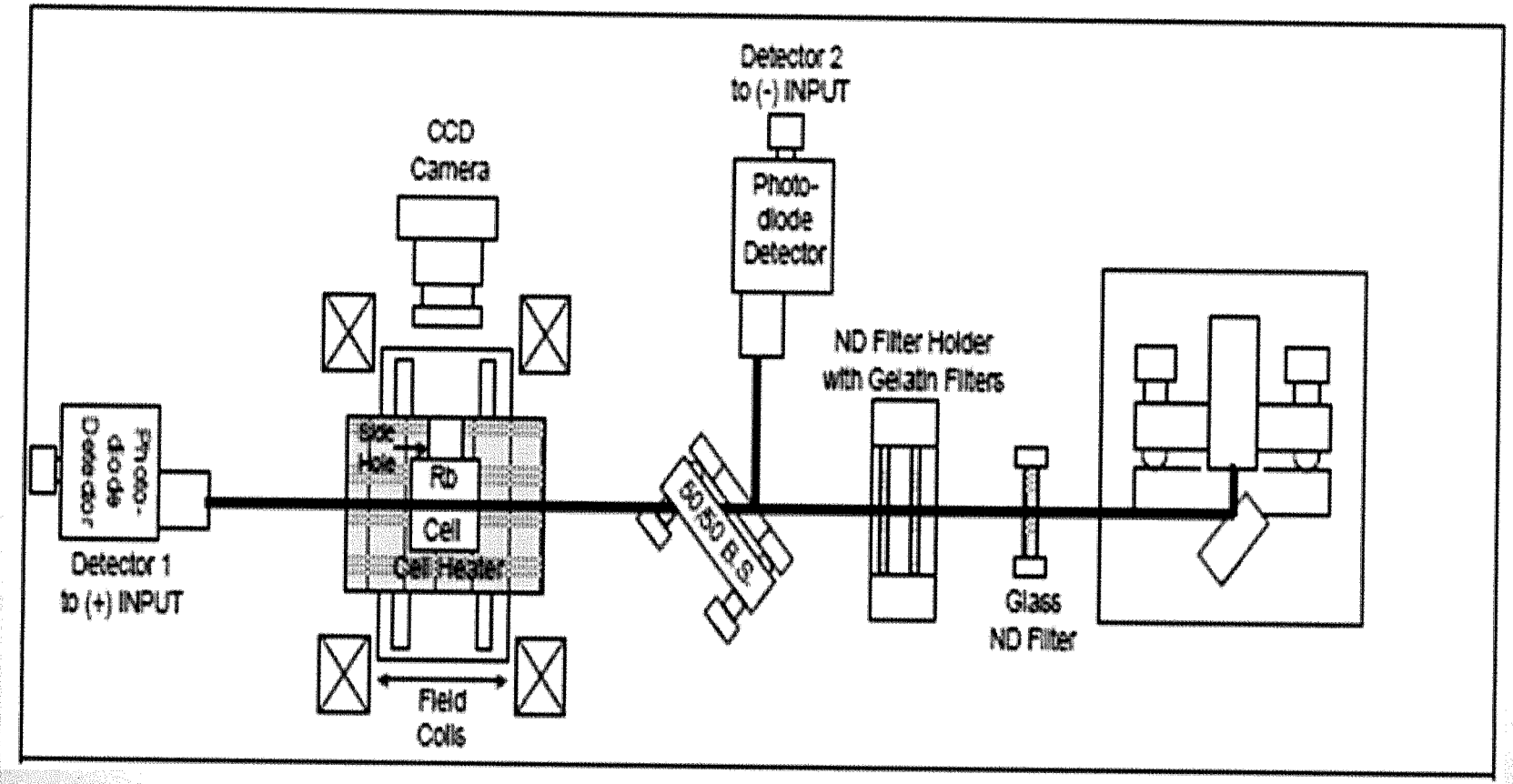
Lower trace (channel 2) shows Detector output.

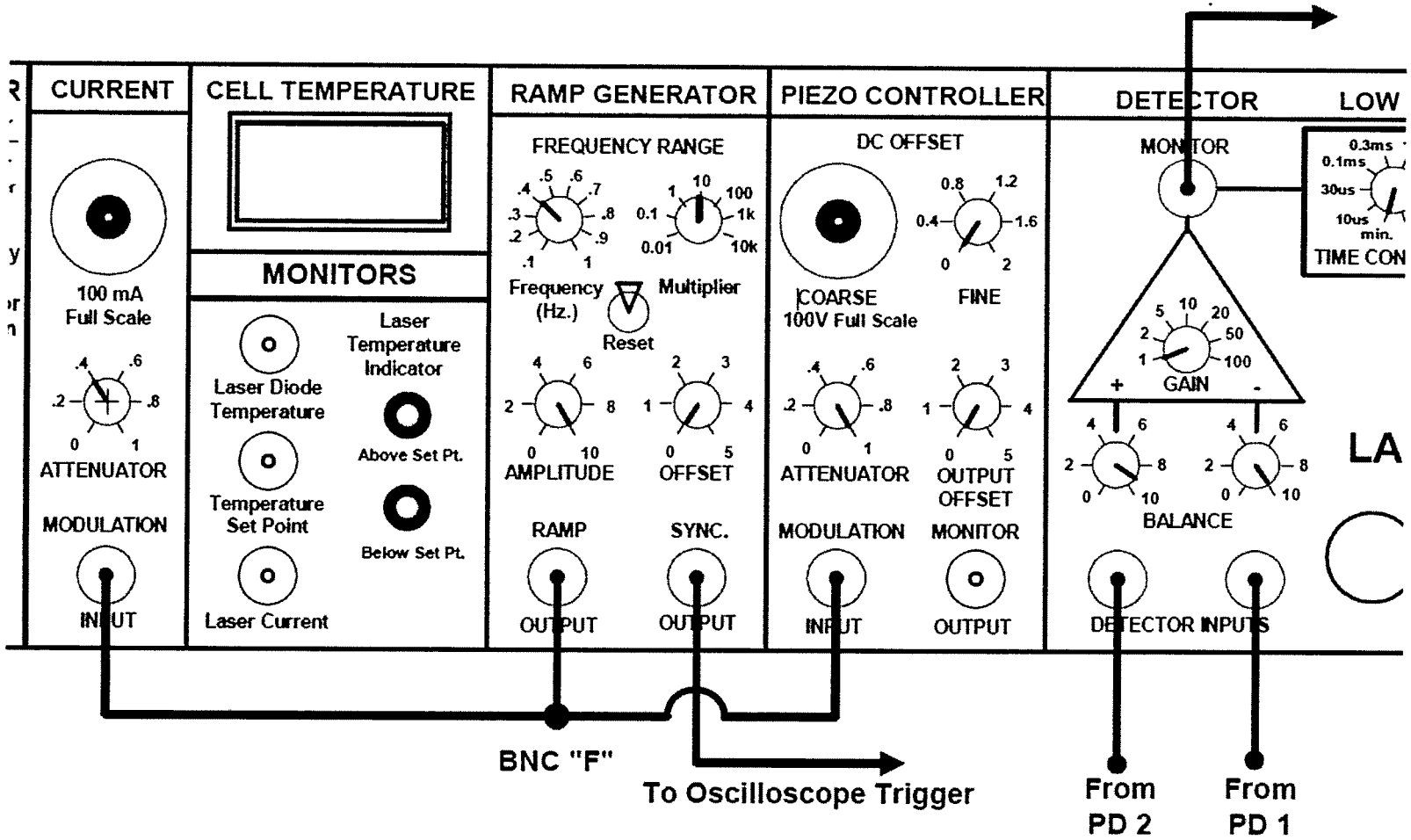


- Set the laser CURRENT ATTENUATOR knob to zero. Attach the BNC splitter "F" connector to the RAMP OUTPUT on the RAMP GENERATOR. Plug one BNC from the RAMP OUTPUT to the MODULATION INPUT of the PIEZO CONTROLLER, and the second BNC from RAMP OUTPUT to the CURRENT MODULATION INPUT.
- Turn the ramp generator amplitude up to maximum, and watch what happens when you turn up the current attenuator knob. With some tweaking you should be able to produce a full trace over the Rb spectrum.
- Use the oscilloscope invert function used to show the trace in what looks more like an absorption spectrum. We get a full trace over the Rb spectrum as shown:



Now we need to compare the laser beam that passed through the Rb vapor, and the one that is directly detected. In order to do this, We need to install a 50/50 Beam splitter, so we need a second photodiode detector to intercept the beam that has been split off by the Beam Splitter.




CURRENT
CELL TEMPERATURE
RAMP GENERATOR
PIEZO CONTROLLER
DETECTOR
LOW
100 mA
Full Scale
ATTENUATOR
MODULATION
INPUT
MONITORS
Laser Diode
Temperature
Temperature
Set Point
Laser Current
Laser
Temperature
Indicator
Above Set Pt.
Below Set Pt.
FREQUENCY RANGE
Frequency
(Hz.)
Multiplier
Reset
AMPLITUDE
OFFSET
RAMP
SYNC.
OUTPUT
OUTPUT
DC OFFSET
COARSE
100V Full Scale
FINE
ATTENUATOR
OUTPUT
OFFSET
MODULATION
MONITOR
INPUT
OUTPUT
MONITOR
0.3ms
0.1ms
30us
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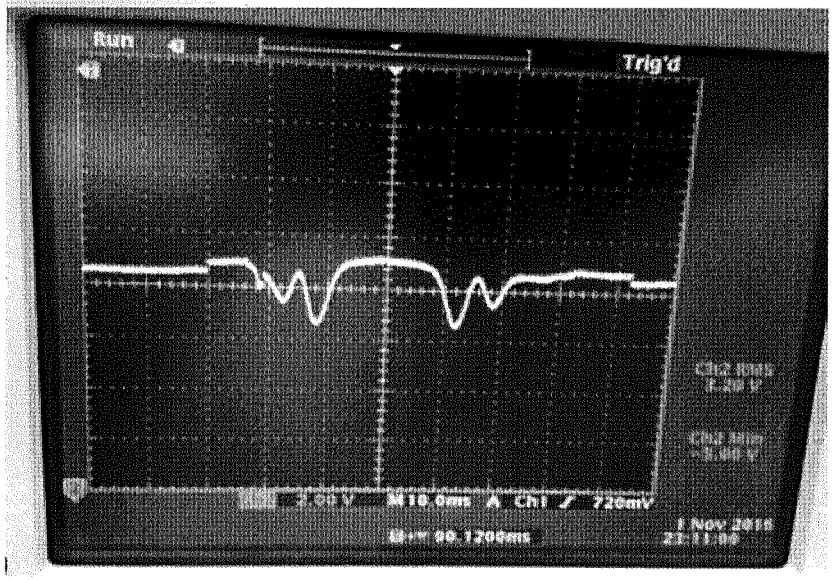
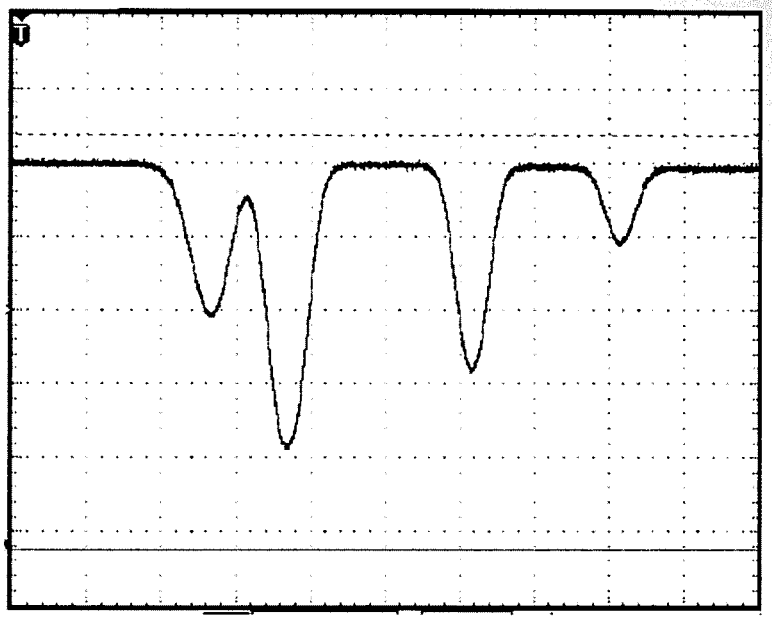
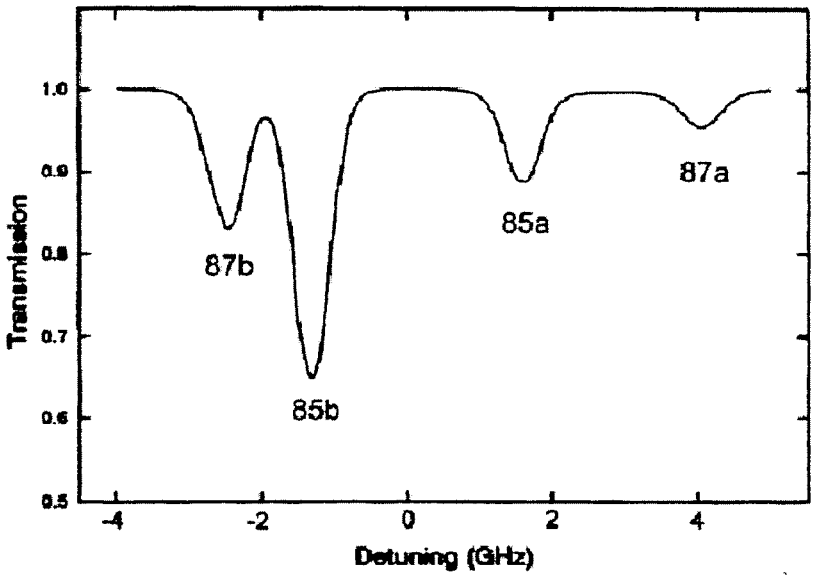
LA
BNC "F"
To Oscilloscope Trigger
From
PD 2
From
PD 1





❖ Conclusion

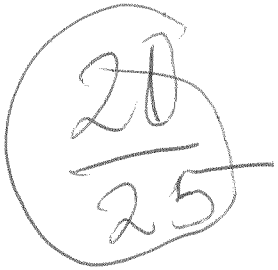
In this experiment, we used the laser diode spectroscopy to show how the energy levels are splitted in an atomic system. The resultant graph we get for the four absorption lines (Figure 12) is very similar to the theoretical one



Optical Pumping

Student : Ahmad Al-Jama

Supervisor : Dr.Akhtar Naqvi

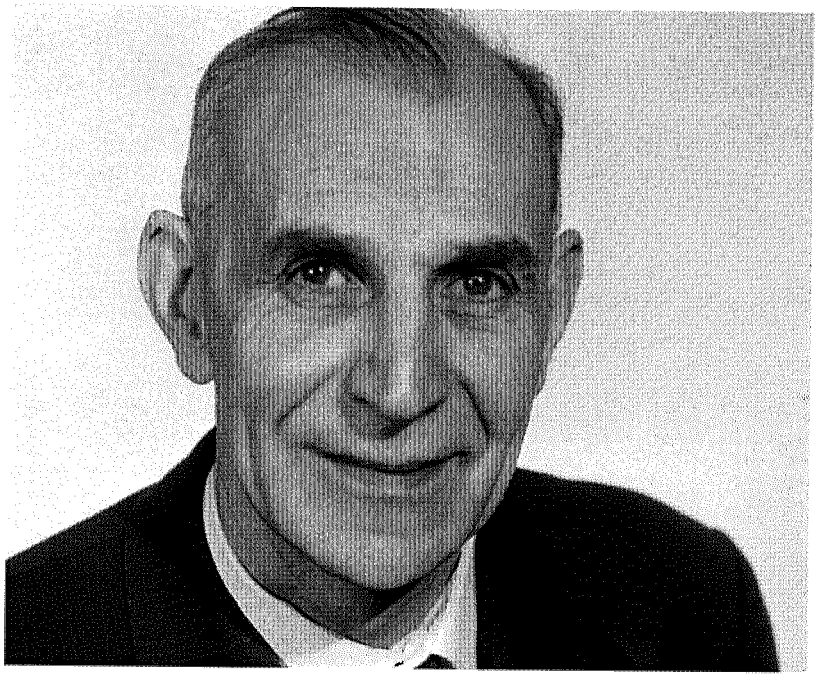


Outline

- Introduction
- Theoretical Background
- Experimental
- Results and Discussion
- Conclusion

Introduction

- Optical pumping is the process that uses photons to change the distribution of the stated occupied by a collection of atoms.
- In 1966, Alfred Kastler won a Nobel Prize for his work on optical pumping.



Introduction

- Rubidium has the electron configuration :

  $1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 5s$

- This means it's a Hydrogen-like atom.
- For such atoms, the complete inner shells can be ignored.

Theoretical Background

- Fine Structure :

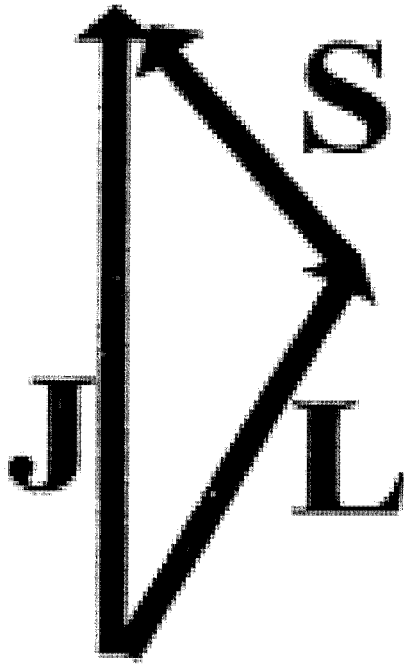
  Results from **J = S + L**

- Hyperfine Structure :

  Results from **F = I + J**

- The Zeeman Effect :

$$\Delta E = g_F \mu_0 B M_F$$



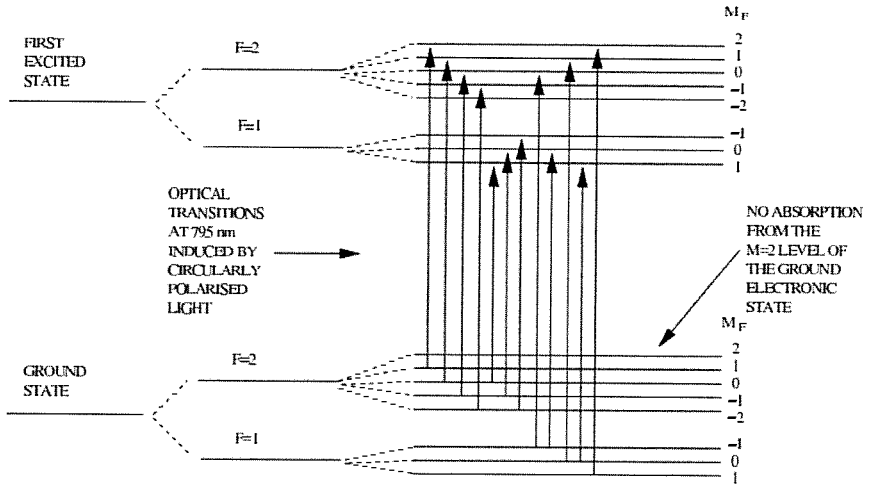
Theoretical Background (Cont'd)

- Absorption :

$$I = I_0 e^{-\sigma_0 \rho l}$$

- Optical Pumping :

Using circularly polarized light to excite electrons where they can no longer be excited.



Experimental Procedure : Equipments

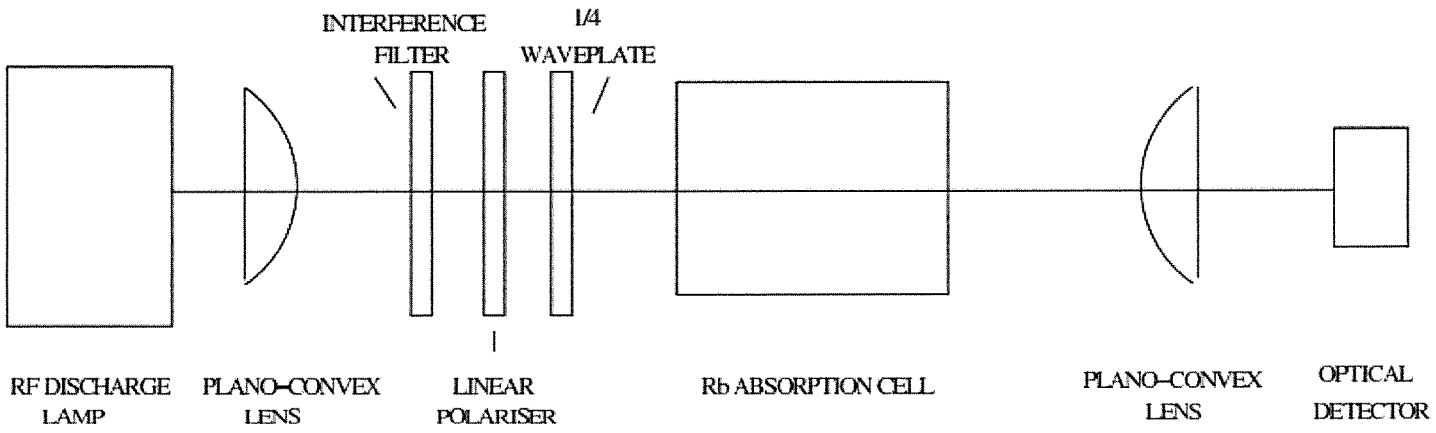
- Rubidium Discharge Lamp : Filled with Rb gas and Xenon Buffer Gas.
- Lenses : One used to collimate the beam. The other used to focus it into the detector.
- Filter : Excludes all lines except the near-IR 795 nm line.
- Polarizer : Produces linearly-polarized light.
- ¼ Waveplate : Produces circularly-polarized light.

Experimental Procedure : Equipments (Cont'd)

- Cell and heater : The cell is an insulated perspex cylinder with a bulb of rubidium and neon buffer gas. The bulb can be heated to change the Rb pressure and density.
- Magnetic field coils : The vertical field is to cancel the local field due to the Earth's magnetic field. The horizontal field is for the Zeeman effect and the sweep field is for viewing the B =0 resonance.
- RF coils and signal generator : the RF magnetic field coils are located on the cell. The field is produced by a signal generator plugged into the electronics box.

Experimental Procedure : Equipments (Cont'd)

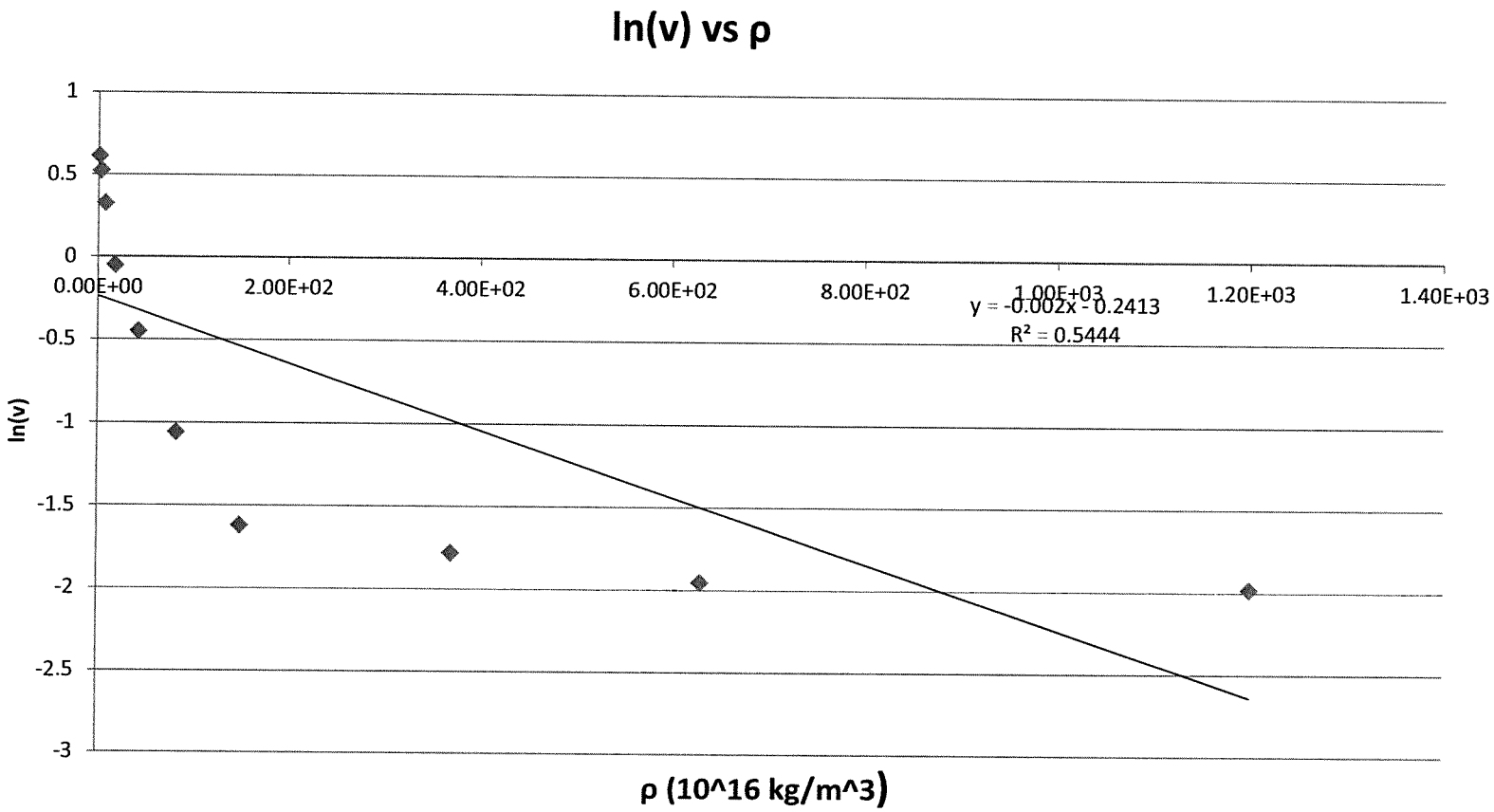
- RF coils and signal generator : the RF magnetic field coils are located on the cell. The field is produced by a signal generator plugged into the electronics box.



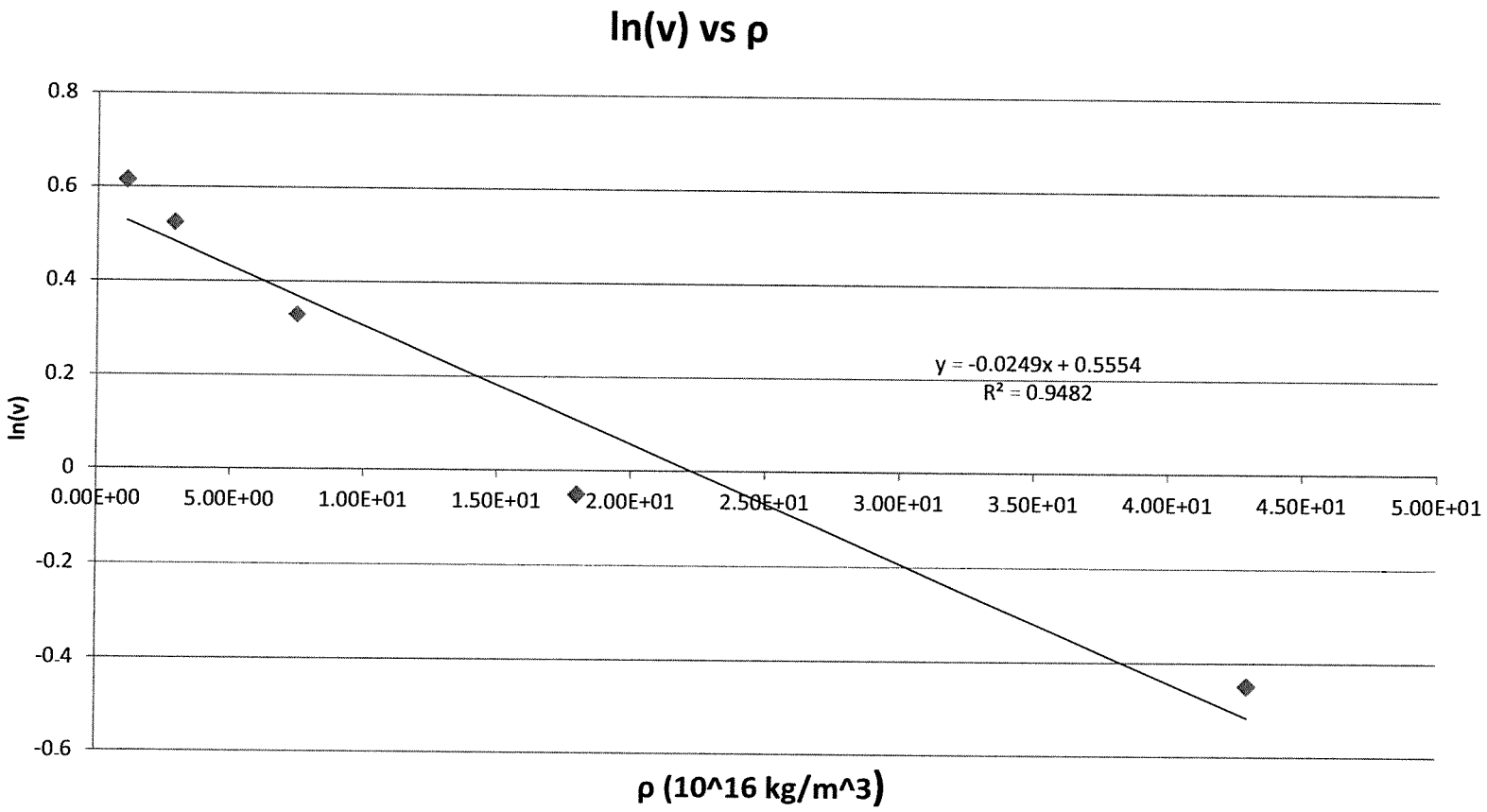
Experimental Procedure : Absorption Cross Section

- We used the optical set-up in the last slide ***without*** the polarized and the ¼ plate.
- We sat the cell's temperature to different values between 300 and …. (10 K steps), and measured the voltage at each temperature.

Results and Discussion



Results and Discussion



Conclusion

$$\sigma = \frac{0.0249}{0.025 * 10^{16}} = 1.00 * 10^{-16}$$

Thanks for listening

Electron Spin Resonance

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Senior Physics Laboratory-(PHYS403) Winter2016
(Term 161)
ID/201246360
Instructor/ Dr. Akhtar A. Naqvi
Assistant/ Tyrence Engalla

20/25

Outline

- *OBJECTIVES*
- DEFINITION
- THEORY
- INSTRUMENTATION
- EXPERIMENTAL PROCEDURE
- EXPERIMENTAL RESULT
- CONCLUSION

- ***OBJECTIVES:***
- looking for the "spin-flip" transition of a free (unpaired) electron exposed to a magnetic field.
- Measure g, a dimensionless quantity that relates the difference in energy between two levels and the magnetic field present

- It is also called electron paramagnetic resonance (EPR) or electron magnetic resonance (EMR).
- Is a branch of absorption spectroscopy in which radiation of microwave frequency is absorbed by paramagnetic substances.
- It was invented by Zavoisky in 1944.

Definition

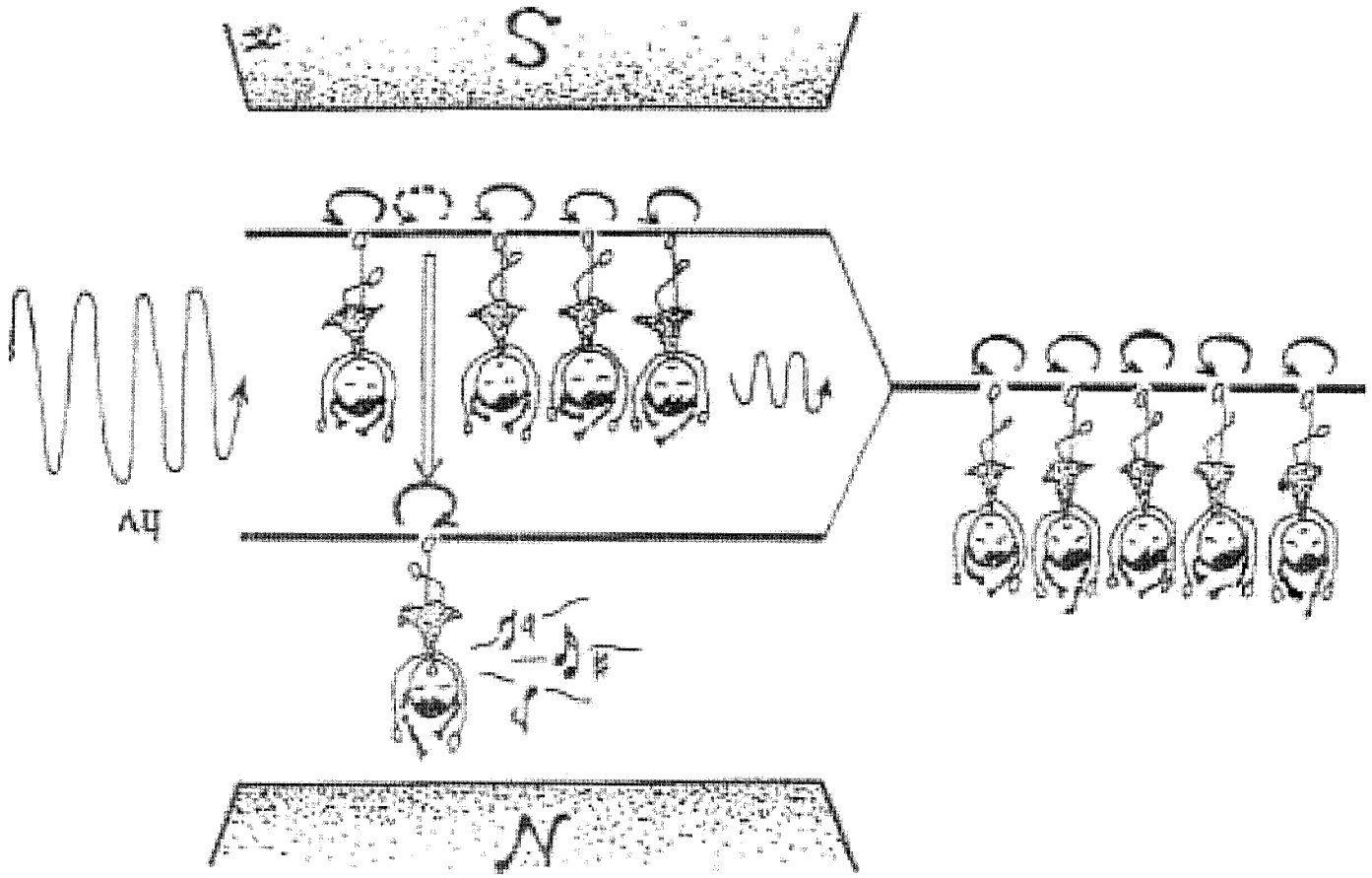
Comparison of ESR with NMR

NMR	ESR
• Different energy states are produced due to the alignment of the nuclear magnetic moments relative to applied magnetic field and the transition between these energy states occurs on the application of an appropriate frequency in the radio frequency region. • NMR absorption positions are expressed in terms of chemical shifts. • Nuclear spin spin coupling causes the splitting of NMR signals.	• Different energy states are produced due to the alignment of the electronic magnetic moments relative to applied magnetic filed and the transition between these energy states occurs on the application of an appropriate frequency in the microwave region. • ESR absorption positions are expressed in terms of "g" values. • Coupling of the electronic spin with nuclear spins(hyperfine coupling) causes the splitting of ESR signals.

- The energy levels are produced by the interaction of the magnetic moment of an unpaired electron in a molecule ion with an applied magnetic field.
- ESR spectrum is due to transition these energy levels by absorbing radiations of microwave frequency.

THEORY

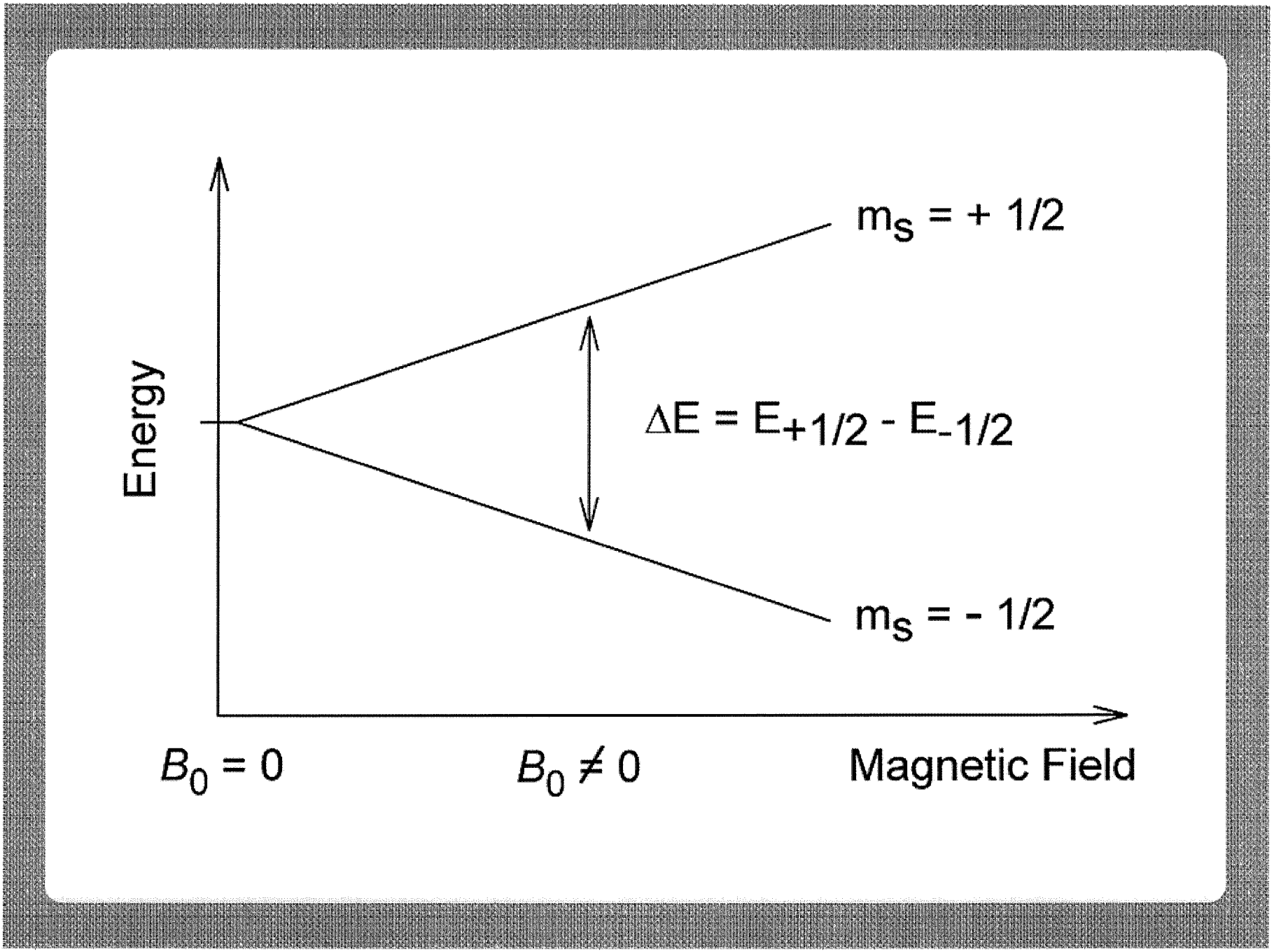
- Like a proton, an electron has a spin, which gives it a magnetic property known as a magnetic moment.
- When an external magnetic field is supplied, the paramagnetic electrons can either orient in a direction parallel or antiparallel to the direction of the magnetic field
- This creates two distinct energy levels for the unpaired electrons.


S
N

- For an electron of spin s=1/2, the spin angular momentum have values of

  m_s= +1/2 or -1/2
- In the absence of magnetic field, the two values give rise to doubly degenerate energy levels(same energy).

  The low energy state will have the spin magnetic moment alligned with the field (m_s= -1/2), and high energy state - opposite to field (m_s= +1/2).


Energy
m_s = + 1/2
$\Delta E = E_{+1/2} - E_{-1/2}$
m_s = - 1/2
$B_0 = 0$
$B_0 \neq 0$
Magnetic Field