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Physics Department

PHYS-403: Experimental Physics-II

NMR: Nuclear Magnetic Resonance

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201725010

To
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Contents

1 INTRODUCTION

1.1 Background

Nuclear Magnetic Resonance (NMR) is a powerful analytical tool that has found applications in a variety of fields such as medicine, chemistry, biochemistry and materials science. It is a physical phenomenon in which nuclei of atoms respond to an applied external magnetic field in order to determine the atoms' chemical structure and environment by altering their spin states. The technique is both label-free and non-destructive, making it possible to study dynamic processes with unprecedented precision. In addition, NMR can detect subtle differences between molecules that are otherwise difficult to separate or distinguish. Given its potential to shape how we understand complex interactional processes at atomic level, NMR remains an important source of knowledge for the scientific community.

1.2 Theory

Magnetic resonance can be seen in systems which have both a magnetic moment and angular momentum. Most of the stable nuclei in ordinary matter possess these properties. In terms of classical Physics, nuclei act like small spinning bar magnets. For this instrument, we will focus on two nuclei; the hydrogen nucleus which is made up of one proton and the fluorine nucleus which consists of both protons and neutrons. Both nuclei can be thought of as small bar magnets with a magnetic moment μ paired with an angular momentum J, related by the vector equation:

$$\mu = \gamma J$$

1.3 Objectives

We have two main targets to hit in this experiment. For different materials we will:
1. Calculate the relaxation time ($T1$), which concerned with spin-lattice interactions.
2. Calculate the relaxation time ($T2$), which concerned with spin-spin interactions.

2 EXPERIMENTAL SET-UP

Main components are (as shown in Figure.1 & Figure.2):

1. Permanent Magnet
2. PS2 Controller
3. Mainframe
4. Oscilloscope
5. Samples (H_2O, light mineral oil, heavy mineral oil & water w/t $FeCl_3$)

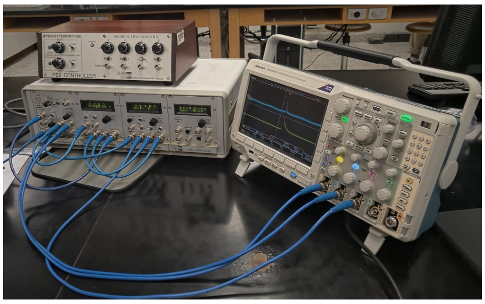

Figure 1: The PS2, the Mainframe and the Oscilloscope

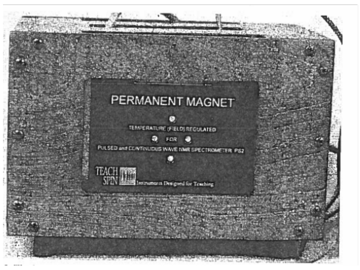

Figure 2: Permanent magnet

Sample	τ for T1 (ms)	τ for T2 (ms)	Period (ms)
light mineral oil	$30 - 200$	$10 - 40$	200
heavy mineral oil	$50 - 150$	$6 - 60$	200
Pure water	$(1.7 - 3)x10^3$	$8 - 140$	510^3
water w/ $FeCl_3$	$240 - 600$	$410 - 100$	800

Table 1: The specific values of the Parameters

2.1 PROCEDURE

We have followed the next steps for obtaining the required results:
1. connect all wires correctly
2. warm-up the magnet
3. calibrate the Oscilloscope using the RF "pick-up probe" (see Figure.3)
4. after calibration start shimming (a process to elongate the magnets)
5. Once the calibration & the shimming are done successfully, start the experiment:
6. Insert the required sample
7. Adjust the parameters of the Mainframe as indicated in Table.1
8.Using the oscilloscope, start looking for the regions where the two peaks separate
9. record all the values of τ for some a certain step you choose
10. Analyze your data

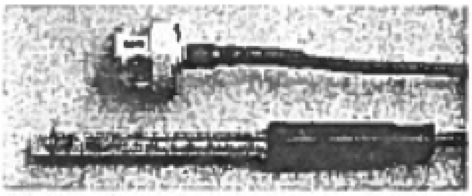

Figure 3: RF pick-up probe

2.2 Results & Discussion

For obtaining T1 we are going to use the following equation:

$$ln[\frac{M_{eq} - M(\tau)}{2M_{eq}}] = -\tau/T1$$

While for obtaining T2 we are going to use the following equation:

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

For Light mineral oil:

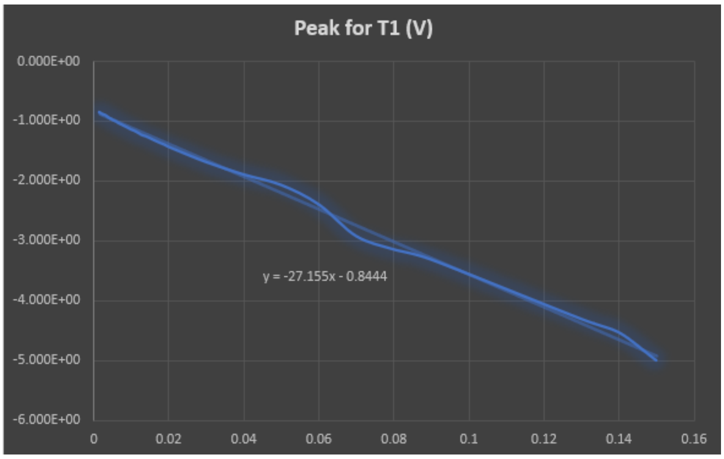

Figure 4: for V(τ) vs. τ , slope is $-1/T_1$

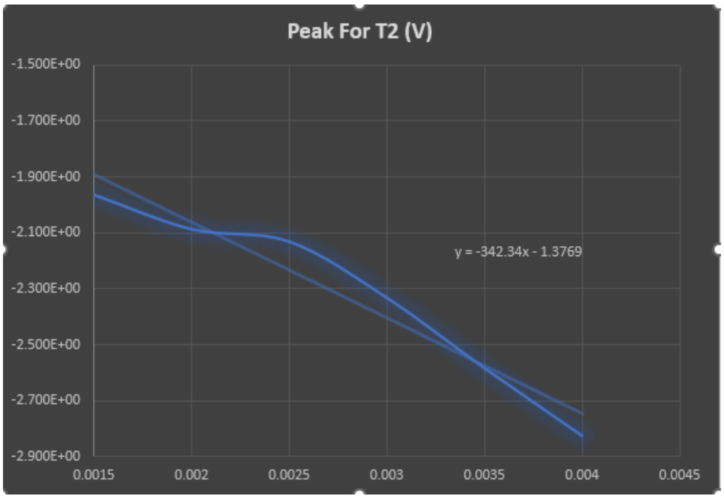

Figure 5: for V(τ) vs. τ , slope is $-2/T_2$

Using given equations and the plotted values , **for light mineral oil**, we may obtain:

$$T1 = 1/27.155 = 37ms$$

$$T2 = 2/342.34 = 5.8ms$$

For Heavy mineral oil:

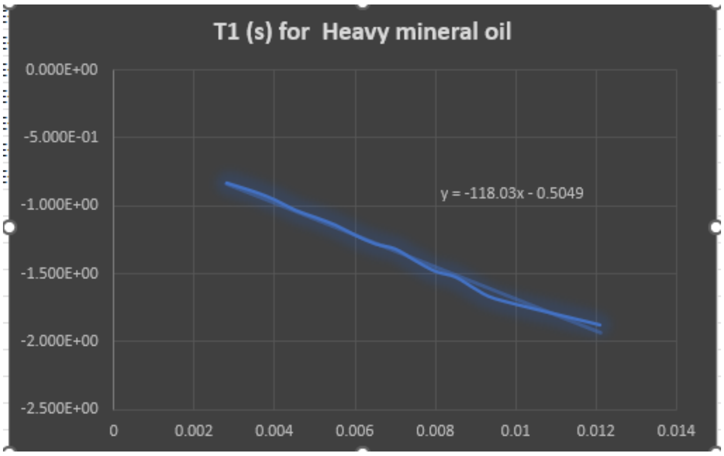

Figure 6: for V(τ) vs. τ , slope is $-1/T_1$

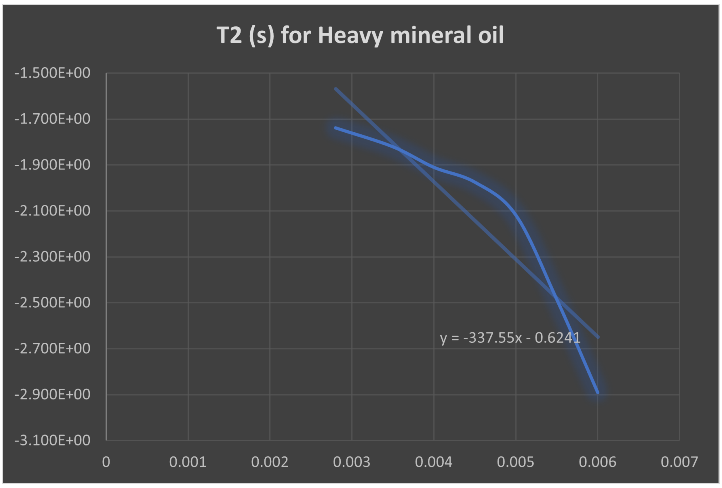

Figure 7: for V(τ) vs. τ , slope is $-2/T_2$

Using given equations and the plotted values , **for heavy mineral oil**, we may obtain:

$$T1 = 1/118 = 8.5ms$$

$$T2 = 2/342.34 = 5.9ms$$

For Impure water:

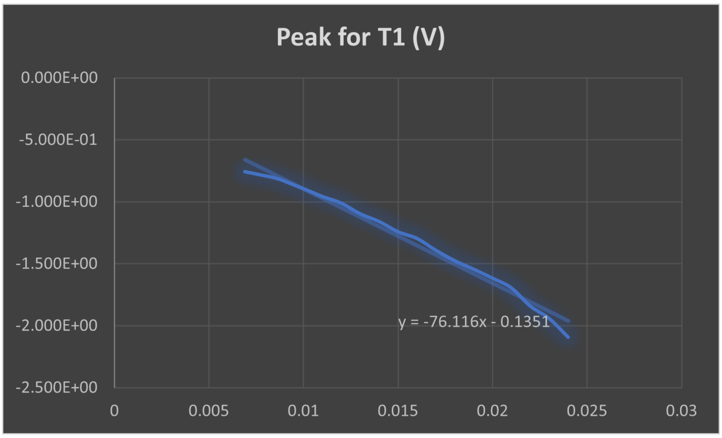

Figure 8: for V(τ) vs. τ , slope is $-1/T_1$

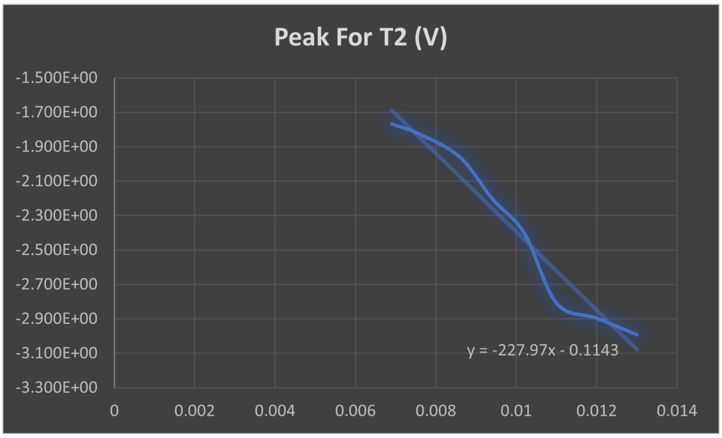

Figure 9: for V(τ) vs. τ , slope is $-2/T_2$

Using given equations and the plotted values , **for impure water**, we may obtain:

$$T1 = 1/76 = 13ms$$

$$T2 = 2/228 = 8.8ms$$

For Pure water:

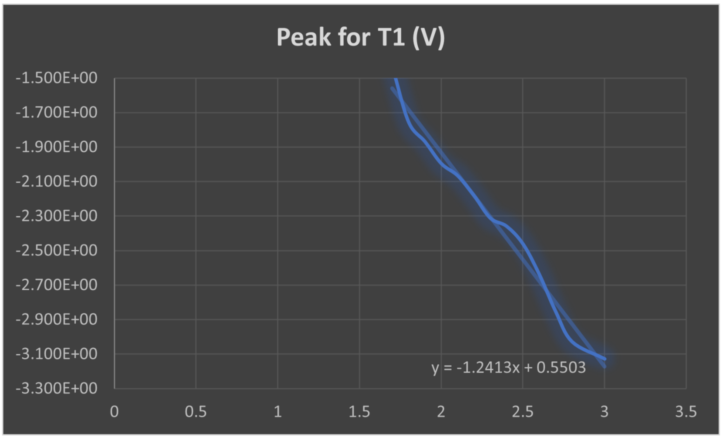

Figure 10: for V(τ) vs. τ , slope is $-1/T_1$

Using given equations and the plotted values , **for pure water**, we may obtain:

$$T1 = 1/1.2 = 830ms$$

$T2 =$ "we were not able to detect/track T2 for pure water."

2.3 discussion

The answers for the questions stated at the end of NM(1-2) file:
Q.1 The Larmor precessional frequency changes in the same direction (i.e. increases) with the magnetic field since increased magnetic field produces more torque on the angular momentum of the particle, causing it to precess faster. This is due to the basic physics principle of angular momentum: angular momentum is conserved, and so any force that acts upon a spinning wheel will cause it to change its direction of rotation rather than its speed. In this case, the increased magnetic field effectively exerts more torque on the spinning wheel which changes its direction of spin more quickly (i.e. resulting in a higher frequency).
Q.2 The cue ball is spinning around its axis of symmetry, which means that there is no angular momentum acting on any other axes than its own. This makes the precession movement impossible since there is no external force acting on any axis to make the ball move differently in space.
Q.4 The gyromagnetic ratio of the cue ball is zero, because it does not contain any magnetic charge. The gyromagnetic ratio of a proton is $2.675X10^8$ rad $T^{-1}s^{-1}$.
Q.5 The relaxation times of spin-spin and spin-lattice interactions allow us

to determine the rate at which molecular processes occur in a sample. By understanding how these interactions relate to specific chemical reactions or processes, we can better understand the chemistry of a sample or observe changes in reaction rates over time. Furthermore, since NMR spectroscopy depends upon relaxation times in order to create proton or carbon images, knowledge of those relaxation times is essential for successful spectroscopy.

Q.6 The relaxation time in NMR is affected by several factors, including the magnetic field strength, the gyromagnetic ratio of the nucleus being studied, and other environmental factors such as temperature, pH and viscosity. The size of the molecules being studied can also affect relaxation time, as larger molecules tend to have longer relaxation times due to increased motional averaging. Relaxation time is also affected by spin-spin interaction between protons or between different nuclei, which can create increased motion in a localized area and thus reduce the average relaxation time.

Q.8 Clearly, pure water has the highest relaxation time while light mineral oil has the least relaxation time. This due the different sizes of molecules. Surely, water in this case has larger molecule than that of light mineral oil.

Q.9 No, it is not but for both oil samples the percentages are around each other.

Q.10 The addition of FeCl3 to water affects the relaxation time by increasing the ionic strength of the solution. FeCl3 is a salt that dissociates into positively charged cations (Fe3+) and negatively charged anions (Cl–), thus increasing the concentration of ions in the solution. This increases the rate at which protons move through the solution, resulting in an increase in overall relaxation times.

Sample	T1 (ms)	T2 (ms)
light mineral oil	37	5.8
heavy mineral oil	8.5	5.9
Pure water	830	–
water w/ $FeCl_3$	13	8.8

Table.2: Summary of the findings

3 CONCLUSION

The data obtained from the NMR experiment showed that the sample contents were found to be in agreement with what was expected, confirming that the molecular structure was as predicted. The experiment has proven to be an invaluable tool for research into the molecular structure of compounds and its use is widespread among scientists studying physics, chemistry and biochemistry. By providing precise structural information, it has allowed scientists to better understand how different molecules interact with each other and how their structure influences their function. As a result, NMR experiments are essential for advancing our knowledge of chemical methods and contributing to our understanding of various processes like drug metabolism, proteins, enzymes and small molecules.

4 REFERENCES

[1] LAB MANUAL