

LAB: Electron-Spin-Resonance / Proton-Spin-Resonance

Equipment:

Spin Cell and Mount, Accessories, Console, and transformers

Analog oscilloscope

Many Banana cables; 2 BNC-Banana Plug connector

2 Pasco Voltage Sensors

Small screw drivers

Pre-lab:

Explain in detail how electron-spin resonance (ESR) works. How is ESR applied? Use internet resources.

Electron-Spin-Resonance (ESR)

Set-up, refer to instructions from 8.1 in manual for illustrations

- Insert the pole face **Rings** into Spin Cell and Mount.
- Loosen Gray Knobs on side of Spin Cell and Mount
- Hold the Scan Coil 2562 so that the arrow points into the same direction as on the surface of the Spin Cell unit. Insert the tubular steel core into bore of the coil. Be sure that the open end of each core interfaces with a pole face ring.
- Plug the red and black leads into surface panel in occurrence with color coding.
- Repeat with mirrored orientation with second coil.
- Tighten Gray Knobs
- Insert Electron Probe into front of Spin Cell and Mount
- Connect each 12V Power Plug to bottoms of Spin Cell and Mount and Console
- Connect white cable of Spin Cell and Mount to Console
- Connection to oscilloscope:
BNC-Bananan Plug adapter: RED is signal input; BLACK is ground.
X-axis, signal Channel 1: on console, fast, Channel 1
Y-axis, signal Channel 2: on console, fast, Channel 2
- From ground of console to ground of Channel 2 and Channel 1.
- Oscilloscope settings:
Time: X-Y axis
Channel 1& 2 on DC mode
- Pasco settings:
Channel 1, slow, of console to A on Pasco Interface
Channel 2, slow, of console to B on Pasco Interface
- Ground the Pasco Interface with ground on console

Procedure 1: Electron-Spin-Resonance:

At a given frequency (LO, MID, HI) a B-field is swept from 0 to 3.67 mT (output 1 → output 0-1 Volt). At the correct B-field value the sample absorbs energy from the MHz-frequency circuit, exactly when an electron spin-transition is induced. This energy loss is shown in a positive peak at output 2 from the console.

- Use orange sample
- IMPORTANT: turn knob of sensitivity on probe mount until you find signal
- Feed signal into computer interface (use two voltage probes / slow scan)
- Three graphs for 3 frequency settings:
LO = 45 MHz
MID = 60 MHz
HI = 75 MHz
- Analyze the 3 graphs and get the B-field for which the resonance occurs!
- For each graph, calculate the g-value.

Proton-Spin-Resonance

Set up 2: refer to instructions from 9.1 in manual for illustrations

- Remove sample
- Remove Electron Probe
- Unscrew Gray Knobs
- Remove tabular steel core
- Remove pole face rings
- Insert pole face **discs**
- Insert Zeeman magnet into holders on back end of the Spin Cell and Mount, such that the metal rests on the lab table.
- Firmly force the keeper, black center of the Zeeman magnet, by pushing down with both thumbs while using fingers curled round the magnet cores to pull magnet assembly upwards and clear.
- Slid Scan Coils onto cores of Zeeman magnet assembly, be sure Coils are plugged in correctly
- Push coils and Zeeman magnet assembly onto mount over pole face discs
- Tighten Gray screws
- Insert Proton Probe

Procedure 2 Proton Spin Resonance

For proton spin-resonance, the magnetic moment is by a factor of 1836 smaller (m_e / m_p). Thus one needs much higher B-fields to visualize the transition in the MHz frequency regime:

A 300mT constant field is now added to the sweeping field!

The frequency in MID position should be ~13MHz.

- Set-up the experiment
- Use the Glycerine sample (yellow)
- Turn the sensitivity knob until you think it is sensitive
- Remove sample, flip the Proton Probe so that the frequency knob is visible and insert sample.
- Scan frequency until you see a peak (Explanation: the scanning range is much smaller now than for ESR and the large constant bias B-field depends on mounting, temperature and other factors. NOTE: if you do not find a peak, change to HI, make the probe sensitive and scan again)
- Try to make scans of all the three materials
- Estimate the value of the resonance B-field.
- Estimate the g-value for Glycerine.
- If time, record graphs for Polystyrene (green) and PTFE (blue).

For Your Labreport:

- An introduction including theory and relevant formulas for this lab and description of the experiment.
- A sketch of the experimental set-up and the cable connections to the oscilloscope.
- The procedure for the experiment including an explanation of why you perform each task
- The Pasco graphs for each frequency, correctly labeled with units and scale.
- Data table with correct units, including the Frequency, time/measurement scale, volts. The B-field should be shown in the last column
- All calculations!

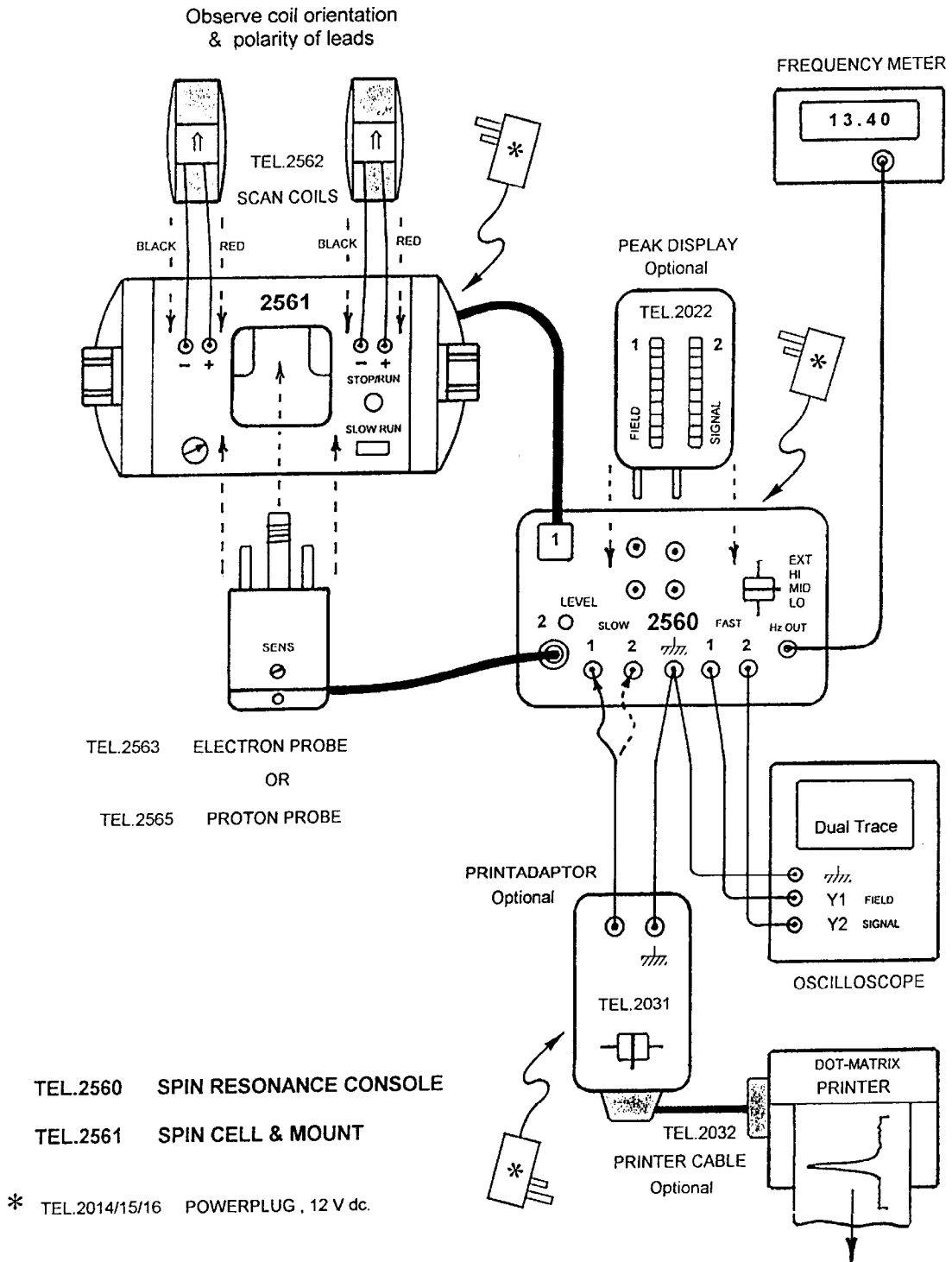
Questions:

- 1) What is the g-factor? What does it mean if the value is 2? If the value is 1?
- 2) Why do the j-values not matter in this measurement?
- 3) Why is ESR limited in its application for most molecules?
- 4) What makes Proton-Spin-Resonance or NMR or MRI such an important tool?

Conclusion:

- Write a short conclusion mentioning your result and discussing possible sources or error.
- Add comments and remarks regarding the lab and its write-up for improvement.

APPENDIX 7 : The instrument set up



4.0 PARAMETERS FOR AN ELECTRON SPIN EXPERIMENT

The energy absorbed by the bar magnet in being forced to the angle θ is $W_0 - W = B \mu_l \cos \theta$ and similarly the energy absorbed in stimulating a spin transition to an excited state is

$$E_j - E_{j'} = B \mu_j \cos \theta = \mu_j B (m_j / j) \quad 11.10$$

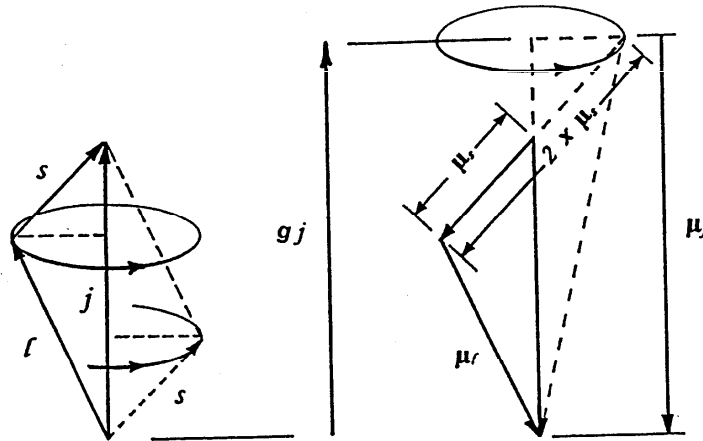


Figure 10 : Vector representation of j and μ_j .

The non-point electron spinning about it's own axis is not analogous to the rotation of a point electron in orbital rotation and so μ_j , the moment of momentum for j , cannot be defined in the same manner as for μ_l in equation 11.07 as a simple multiple of j and μ_B ; furthermore practical evidence reveals many more than the few component lines which are predicted from a theoretical study such as that of Figure 06 . This indicates that the magnitude of the splitting is not identical in the higher and lower states and seems dependent on the values of j and l ; in some cases such as the alkalis, the splitting between the ground states is observed as being as much as twice what might be expected.

The hitherto simple relationship of $-j \mu_B$ for the moment of momentum was therefore varied to

$$\mu_j = -g j \mu_B \quad 11.11$$

where g , called the Landè splitting factor , is a rational number which depends upon the values of j and l and has values of 1 when $s = 0$ and 2 when $l = 0$; the mathematical derivation is detailed in Appendix 6 . This effectively assumes that the magnetic moment of the electron due to it's spin , μ_s is one whole Bohr magneton, which accords with practical observations and not one-half as might be expected if μ_j were to exactly equal $-j \mu_B$; this result can also be derived theoretically. Substituting in equation 11.10

$$E_j - E_{j'} = m_j g B \mu_B \quad 11.12$$

and there are m_j energy levels separated by the quantised energy value $g B \mu_B$.

If energy is injected into the system in an attempt to excite a spin transition , it will be preferentially absorbed if it's frequency ν satisfies the relationship

$$h \nu = g B \mu_B \quad 11.13$$

This is a process where one vibration is produced in response to another of equal frequency and, as in other physical phenomena it is called Resonance.

EXPERIMENT B.11 - THE EXCITATION OF ELECTRON SPIN TRANSITION :

TIME - 40 mins	TEL.2560+ , TEL.2561+ , TEL.2562 , TEL.2563 , TEL.2022	+TEL.2014/15/16
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MONITORS REQUIRED : OSCILLOSCOPE - Dual Trace.
 PRINTADAPTOR TEL.2031 & DOT-MATRIX PRINTER
 or
 CHART RECORDER.
 FREQUENCY METER (optional) - 80 kHz with 4-digit resolution.

11.01 Establish the work station of Appendix 7 - the pull-out of the last page :

Locate the PEAK DISPLAY , TEL.2022 in the sockets on the surface of the Console and connect the Printadaptor (or chart recorder) and the Oscilloscope to the Channel 1 and Channel 2 array of 4-mm output sockets ; optionally connect to the Frequency Meter using the 2-mm co-axial socket, $\pm 10^3$ Hz.

11.02 Mount the Scan Coils, TEL.2562 and Cores ; see para. 8.1 , page 13 :**11.03 Location of the Electron Probe, TEL.2563 ; see Figures 13 and 14 , page 14 :**

With the cable facing **downwards**, carefully insert the **coil tube** protruding from the Electron Probe housing into the **cavity at the front** of the Cell column and secure the assembly by pressing home the fixed pair of 4-mm plugs ; connect the co-axial cable to the BNC socket marked **probe** at Channel 2 on the surface panel of the Spin Resonance Console.

11.04 Initial set-up :

⇒ **Set Frequency Meter** to read 70 kHz with 4 figure resolution (gate time 0.1 s).

Switch on the mains power to the two Powerplugs and observe

- ◆ on the Console 2560 , that the **signal level indicator** LED of Channel 2 is illuminated , **red** and using the slider button , select Hz to **MID** ,
- ◆ on the Cell Mount 2561, that the **stop/run** LED is active, **red/green** ,
- ◆ on the Probe 2563 , that the **power on** LED is lit, **red** , and use a small screw driver to reduce the sensitivity control , **SENS** to the minimum setting , **fully anti-clockwise** ,
- ◆ the **frequency meter**, if connected , reads approximately **60 kHz** (60 Mhz probe frequency).

⇒ **Set Oscilloscope** : Both Channels - 200 mV / division, dc coupled ; Timebase - 5 ms / division ; Trigger : Source - Channel 1 ; Mode - normal, dc coupled ; Slope - negative.
 Adjust the **trigger level control** to obtain a stable trace as in **Figure 21** .

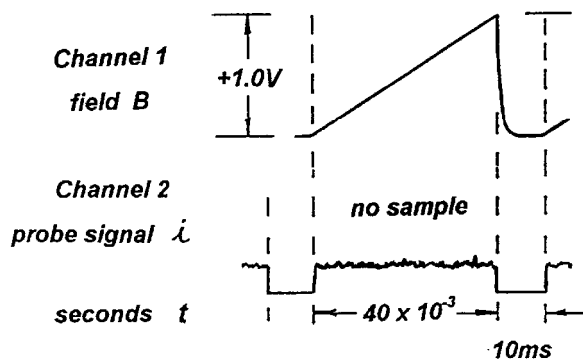


Figure 21 : The two initial traces .

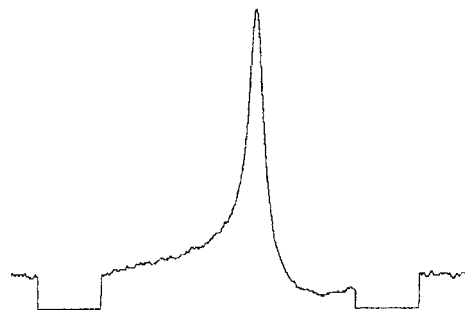


Figure 22 : The Channel 2 resonance peak.

11.05 Obtaining a Resonance Peak :

Carefully insert the DPPH sample phial, **orange** into the cavity at the back of the CELL column.

This electron 'target' is a small sample of the free radical **diphenyl-picri-hydrazyl, DPPH** . This paramagnetic compound has a loosely bound unpaired electron parasitic on a Nitrogen atom which can be excited more easily than a material with a more complete electron shell structure.

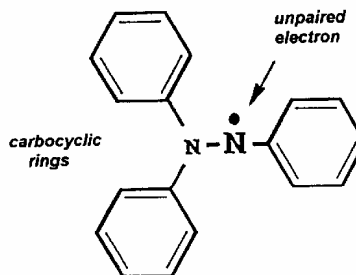


Figure 23 : The free radical - DPPH .

Increase the sensitivity control **SENS** on the top of the Probe housing until the **red signal level LED** of Channel 2 on the Console begins to dim (see para. 8.2). The Oscilloscope should now display a **Resonance Peak** on Channel 2 as in **Figure 22** .

11.06 Replace the DPPH sample with the Reference Phial, **black** and observe the absence of the peak ; the resonant condition is therefore due to the DPPH sample ; remove the Reference Tube and replace the DPPH sample tube.

11.07 RECORD THE VALUES OF FREQUENCY - ν : see para. 8.5 , page 15 :

Set the **Sensitivity** of the data logging device to **1 Volt full scale deflection** and set the **Paper speed** to **5 mm per second** ; save the result on paper and record the frequency or write **MID** on the chart .

11.08 Decrease the **SENS** control to minimum ; on the Console change the **Hz** slide control to **HI** . Observe that the frequency meter reads about **75 kHz**, an increase in probe frequency ν to **75 MHz** .

11.09 Increase the **SENS** control until the **signal level LED** begins to dim ; the display on Channel 2 of the oscilloscope will show the Resonance Peak displaced to the right ; this infers a higher flux density **B** as expected from **Figure 11** ; save the result on paper as from **11.07** above and record the frequency or write **HI** on the chart .

11.10 Repeat **11.08** and **11.09** but with the **Hz** control on the Console changed to the **LO** setting; the probe frequency will be reduced to about **45 MHz** and again write the reading or **LO** on the chart .

The change of frequency from the **MID** to the **HI** and **LO** settings above effects the oscillator level and it is therefore necessary to re-adjust the sensitivity control at each change of probe frequency.

11.11 CALCULATE THE VALUE OF THE MAGNETIC FLUX DENSITY - B :

In order to evaluate the Landè splitting factor **g** a measure must be made of the value of the magnetic field at the moment of resonance.

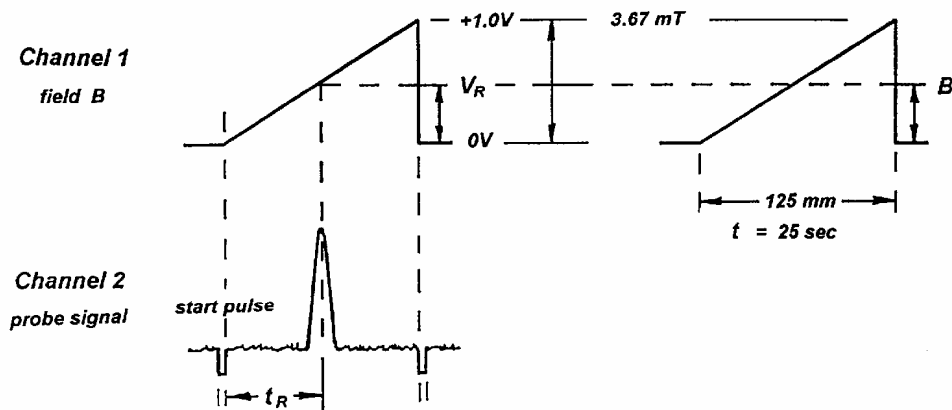


Figure 24 : The value of B at the instant of resonance .

The circuitry in the CELL MOUNT 2561 supplies the current drawn by the SCAN COILS 2562 in the form of a linear ramp from 0 to 250 mA in time t seconds and this, together with their cores generates a magnetic field with a linear sweep from 0 to a maximum of 3.67×10^{-3} Tesla. A signal of from 0 to 1 volt proportional to this field is output as Channel 1 in both SLOW and FAST modes.

The value of B at the instant of resonance can be calculated from a measurement of V_R or of t_R .

$$B = V_R \times 3.67 \times 10^{-3} \text{ Tesla} \quad 11.15$$

or

$$B = t_R/t \times 3.67 \times 10^{-3} \text{ Tesla} \quad 11.16$$

where

$$t = 40 \times 10^{-3} \text{ seconds in FAST mode and} \\ = 25 \text{ seconds in SLOW mode.}$$

11.12 Tabulate the readings of frequency as recorded on the three charts of 11.07 to 11.10 and also the measurements of V_R or of t_R , calculate B and plot the graph of $B = k \nu$, **Figure 25**.

	ν	t_R	t	t_R/t	V_R	B
	Hz	sec			volts	Tesla
MID						
HI						
LO						

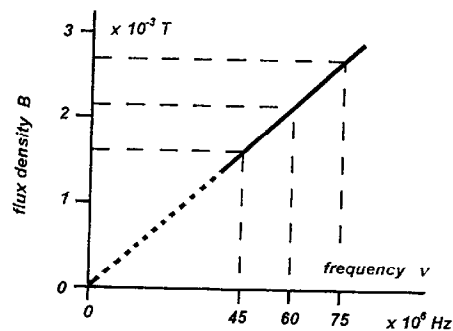


Figure 25 : The graph of $B = k \nu$.

Evaluate k from the graph, substitute in Equation 11.14 and calculate the value of g .

For the sample of DPPH, $g = 2.0036$ with values for h and μ_B as in Appendix 1.

11.13 THE CALCULATION AND IMPORTANCE OF g :

The graph of **Figure 25** is linear and should pass through zero; this alone justifies the theoretical postulation of the intrinsic spin of the electron; this assumes that the value of g is a constant for any given material in the particular phase of the sample.

The Landé splitting factor g is derived from a mathematical treatment of the vectors j , l and s , as shown in **Appendix 6** and so an accurate knowledge of its value leads to the evaluation of the three vectors and therefore the unique energy structure of the electrons in the sample; samples containing different materials when subjected to a more sophisticated ESR experiment, using equipment many times more sensitive and with broader ranges of sweep for both flux and frequency than that of the didactic experiment of **B.11**, will yield a spectrum of resonance peaks in a similar manner to the familiar optical spectrum; **peak intensity** is proportional to the amount of material in the sample.

The rate at which resonance signals decay, called the **relaxation process** determines the pulse width of the signal, usually defined at half-height, see **Figure 26**; modern ESR instruments possess differentiating circuitry to provide a first derivative (dy/dx) which enables a more precise measurement.

The half-width is influenced by the proximity and nature of the surrounding elements and on the temperature of the environment, see next page; analysis of these factors yields comprehensive information regarding the chemical and physical characteristics of the various sample components.

6.0 PARAMETERS FOR PROTON SPIN RESONANCE (PSR) :

The nucleus has mass and charge but does not orbit about any focal point ; it does not therefore have any orbital angular momentum but if , like the electron , it is spinning about its own axis it will exhibit Larmor precession , it will have angular momentum due to this spin and it will be space quantised with a finite number of permitted energy levels ; in the mid nineteen twenties the theoretical physicist and eventual 1945 Nobel prize winner **Wolfgang Pauli** accorded a magnitude of $\frac{1}{2} \hbar$ to this angular momentum , where the vector I is called the **nuclear spin quantum number** ; this will combine vectorially in a quantised manner with J to give

$$F = I + J$$

where F is called the **hyperfine quantum number** .

At that time there was evidence, using optical spectrometers of very high resolving power , of hyperfine structure especially when comparing the spectra of isotopes , where there are an equal number of extra-nuclear electrons but differing atomic masses; the splitting of the spectral lines was extremely small, indicative of minute energy differences and in preference to attempting to reason yet another attribute of the electron this **hyperfine splitting** was considered to be due to **nuclear spin** .

Using a mathematical treatment similar to that of the electron it can be shown that the magnetic moment of the nucleus, μ_I can be defined by the relationship

$$\mu_I = g_I I \mu_N \quad 12.01$$

where g_I is the **Nuclear g - factor** and μ_N is the **Nuclear magneton**.

The Nuclear g - factor , g_I is dependent in a complex manner on the binding of the neutrons and protons within the nucleus and it is not as mathematically predictable as the Landè splitting factor. There exist a number of Tables which have been derived to provide values for both μ_I and g_I but none of these can be considered absolute until the structure of the nucleus is fully defined. The Nuclear magneton μ_N however does compare with the Bohr magneton of equation 11.04 except that , since the mass of the nucleus is due to the protons , the mass of the electron m is substituted by the mass of the proton m_p to give

$$\mu_N = \hbar e / 4 \pi m_p \quad 12.02$$

The mass of the proton is **1836 times larger** than that of the rest mass of the electron , so the Nuclear magneton is **1836 times smaller** than the Bohr magneton and

$$\mu_N = \mu_B / 1836 = 5.05 \times 10^{-27} \text{ J T}^{-1}.$$

Excitation of the nucleus should display $(2I + 1)$ levels in accordance with the restrictions of space quantisation, all separated in proportion to this extremely small energy value for μ_N . As with the electron, if energy is injected into the system in an attempt to excite a nuclear transition , it will be preferentially absorbed if its frequency ν satisfies the relationship

$$\hbar \nu = g_I B \mu_N \quad 12.03$$

The complete experiment conceived to detect Proton Spin Resonance (PSR) and so justify the theoretical postulation of the quantised intrinsic spin of the proton is described in detail in Part 2 : Experiment B.12 - The Excitation of Proton Spin Transition .

EXPERIMENT B.12 - THE EXCITATION OF PROTON SPIN TRANSITION :

TIME - 40 mins	TEL.2560+, TEL.2561+, TEL.2562 , TEL. 2564 , TEL.2565 , TEL.2022
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+ TEL.2014/15/16

MONITORS REQUIRED : OSCILLOSCOPE - Dual Trace.
 PRINTADAPTOR TEL.2031 & DOT-MATRIX PRINTER
 or
 CHART RECORDER.
 FREQUENCY METER (optional) - 80 kHz with 4-digit resolution.

12.01 Establish the work station of Appendix 7 - the pull-out of the last page :

Locate the PEAK DISPLAY , TEL.2022 in the sockets on the surface of the Console and connect the Printadaptor (or chart recorder) and the Oscilloscope to the Channel 1 and Channel 2 array of 4-mm output sockets ; optionally connect to the Frequency Meter using the 2-mm co-axial socket, $\pm 10^3$ Hz.

12.02 Mount the Zeeman Magnet, TEL.2564 and Scan Coils , TEL.2562 ; see para. 9.1, page 15:

The flux density is boosted one hundredfold by the Zeeman Magnet to the order of 300×10^{-3} Tesla , with a small sweep still being provided by the SCAN COILS 2562 . A flux of this magnitude is still only sufficient to influence those materials where there is a relatively large population of atoms with a low atomic weight such as Hydrogen and Fluorine . The VHF radiation ν is reduced to about 13 MHz and the Electron Probe is exchanged for the PROTON PROBE, TEL.2565.

12.03 Location of the Proton Probe, TEL.2565 ; see Figures 13 and 14 , page 14 :

With the cable facing **downwards**, carefully insert the **coil tube** protruding from the Proton Probe housing into the **cavity at the front** of the Cell column and secure the assembly by pressing home the fixed pair of 4-mm plugs ; connect the co-axial cable to the BNC socket marked **probe** at Channel 2 on the surface panel of the Spin Resonance Console.

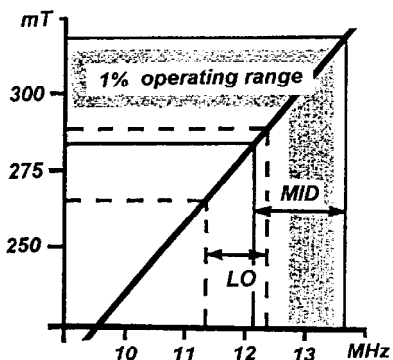
12.04 Initial set-up :

⇒ **Set Frequency Meter** to read 20 kHz with 4 figure resolution (gate time 0.1 s).

Switch on the mains power to the two Powerplugs and observe

- ◆ on the Console 2560 , that the **signal level indicator** LED of Channel 2 is illuminated , **red** and using the slider button , select **Hz to MID** ,
- ◆ on the Cell Mount 2561 , that the **stop/run** LED is active, **red/green** ,
- ◆ on the Probe 2565 , that the **power on** LED is lit, **red** , and use a small screw driver to reduce the sensitivity control , **SENS** to the minimum setting , **fully anti-clockwise** ,
- ◆ the **frequency meter**, if connected , reads approximately **13 kHz** (13 MHz probe frequency).

⇒ **Set Oscilloscope** : Both Channels - 200 mV / division, dc coupled ; Timebase - 5 ms / division ; Trigger : Source - Channel 1 ; Mode - normal, dc coupled ; Slope - negative.
 Adjust the **trigger level control** to obtain a stable trace as in **Figure 21/22** .

12.05 Obtaining a Resonance Peak :

The range over which the magnetic field is scanned by the coils, 3 mT is only about **1%** of the total field 300 mT ; it is evident from equation 11.14 that, in order to produce a resonance signal, the frequency of the probe must be tuned to match the corresponding 1% range . The probe frequency is adjusted to the correct value, 42.5771 MHz/T during manufacture; however if this frequency has been changed or a different magnet is used , the probe frequency may need to be retuned , see para. 12.06 .

Figure 27 : Matching the probe frequency .

Carefully insert the **Glycerine** sample phial, **yellow** into the cavity at the back of the CELL column; on the Console 2560 select **Hz** to **MID** and increase the **SENS** control on the top of the Probe housing until the **red signal level LED** of Channel 2 on the Console begins to dim. The Oscilloscope should now display a **Resonance Peak**. If no Resonance Peak is visible it is necessary to retune the probe frequency; remove the sample phial.

12.06 Withdraw the Proton Probe unit from the Cell column and re-insert it inverted with the cable facing **upwards** thus gaining access to the frequency control labelled **FREQ**. Replace the sample phial and adjust the frequency until a Resonance Peak is observed ; the required frequency will be within the range **12.7 to 13.5 MHz**. Ensure that the **red signal level LED** of Channel 2 on the Console remains illuminated ; if necessary adjust the sensitivity control **SENS** now on the underside of the Probe housing by carefully tilting the entire assembly backwards.

12.07 Remove the sample phial, withdraw and replace the Proton Probe with the **SENS** control facing upwards ; if necessary repeat the procedure of **12.05**.

Loosen the **Dark Grey Knobs** locking the system and study, on the oscilloscope the effect on signal intensity ; re-tighten for maximum intensity and then **save the result onto paper** by repeating paragraphs **11.07** to **11.09** and record on the paper the frequency and the material of the sample, **Glycerine** ; the Glycerine molecule contains 8 Hydrogen nuclei.

12.08 Replace the Glycerine sample with empty Reference Phial, **black** and observe the **absence** of the Resonance Peak ; there may be the witness of a small peak due to resonance of Hydrogen nuclei in the plastic material from which the coil former of the Probe is made.

12.09 Replace the black Reference Phial with the **Polystyrene** sample, **green** and repeat the procedures of **12.05** to **12.07** . The subsequent resonance peak is wider and of reduced amplitude ; the styrene molecule also contains 8 Hydrogen nuclei.

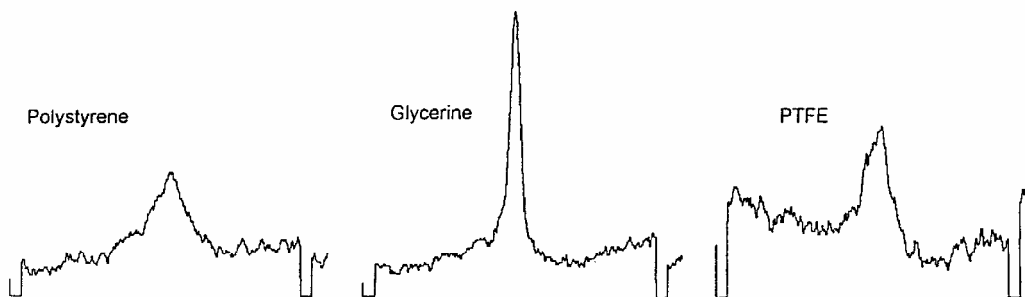


Figure 28 : A comparison of the three resonance peaks.

12.10 Replace the green Polystyrene sample with the **Polytetrafluorethylene (PTFE)** sample, **blue** and repeat the procedures of **12.05** to **12.07** ; resonance of the fluorine protons occurs at a frequency slightly less than that of the previous two samples and it is necessary to retune the Probe frequency as in paragraph **12.06** ; in extreme cases a reduction of the **Hz** selection on the Console 2560 to the **LO** setting may also be required. The resonance peak is smaller in amplitude to that of Glycerine ; the normal PTFE molecule contains 8 Fluorine nuclei.

12.11 CALCULATE THE VALUE OF THE MAGNETIC FLUX DENSITY - B :

The flux density to which the sample in the cell is subjected comprises two components ; that due to the Scan Coils 2562 superimposed on that due to the Zeeman Magnet 2564.

12.12 The field due to the Scan Coils, TEL.2562 :

The circuitry in the CELL MOUNT 2561 supplies the current drawn by the SCAN COILS 2562 in the form of a linear ramp from 0 to 250 mA in time t seconds and this, together with their cores generates a magnetic field with a linear sweep from 0 to a maximum of 3.2×10^{-3} Tesla; this is slightly different to that of the ESR experiment as a result of the different core configuration . A signal of from 0 to 1 volt proportional to this field is output as Channel 1 in both SLOW and FAST modes, see **Figure 29** .

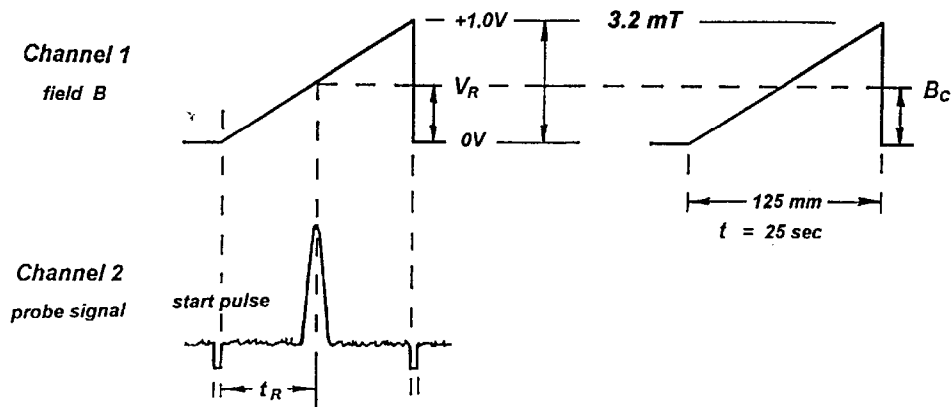


Figure 29 : The value of B_C at the instance of resonance .

The value of B_C at the instant of resonance can be calculated from a measurement of V_R or of t_R .

$$B_C = V_R \times 3.2 \times 10^{-3} \text{ Tesla} \quad 12.04$$

or

$$B_C = t_R / t \times 3.2 \times 10^{-3} \text{ Tesla} \quad 12.05$$

where

$$t = 40 \times 10^{-3} \text{ seconds in FAST mode and} \\ = 25 \text{ seconds in SLOW mode.}$$

12.13 Tabulate the readings of frequency as recorded from 12.05 to 12.10 and also the measurements of V_R or of t_R , and calculate B_C .

Sample	Colour	ν	t_R	t	t_R/t	V_R	B_C
		Hz	sec			volts	Tesla
Glycerine	Yellow						
Polystyrene	Green						
PTFE	Blue						

12.14 The field due to the Zeeman Magnet, TEL.2564 :

The flux density, B_{20} due to the Zeeman Magnet is marked on the shroud of the magnet and is approximately $300 \times 10^{-3} \text{ Tesla}$; the flux is slightly sensitive to temperature and is calibrated at the factory at a standard temperature of 20°C .

The temperature co-efficient of the material of the magnet is $-0.075 \% / ^\circ \text{C}$ so the compensated value of flux density, B_Z is given by

$$B_Z = B_{20} \times [1 - (t_z - 20) \times 7.5 \times 10^{-4}] \quad 12.06$$

where

t_z = temperature of the Zeeman magnet, $^\circ \text{C}$ which must be recorded using a thermometer positioned close to the cores or, for greater accuracy, with a thermocouple taped onto one of the core blocks.

The total field at resonance is then

$$\Sigma B = B_C + B_Z \text{ Tesla} \quad 12.07$$