Atomic and Nuclear Physics

Magnetic Resonance

PHYSICS EXPERIMENT

Electron Spin Resonance

DEMONSTRATE ELECTRON SPIN RESONANCE IN DPPH

- Observe the resonance curve of DPPH.
- Determine the resonant frequency as a function of the magnetic field.
- Determine the Landé *g*-factor for free electrons.

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Fig. 1: Experiment set-up

GENERAL PRINCIPLES

Electron spin resonance (ESR) is based on the energy absorption by substances with unpaired electrons, which are inside an external magnetic field produced by a DC source. The energy is absorbed from a high-frequency AC-generated field which is fed in perpendicular to the field from the DC source. If the frequency of the alternating field is equal to the resonant frequency, the impedance of the transmitting coil filled with the test material changes in accordance with a resonance curve and a peak will be visible on an oscilloscope screen. The cause of resonance absorption is the "tipping over" of the magnetic moments between spin states of a free electron. The resonant frequency depends on the strength of the DC-generated field and the width of the resonance signal is related to the uniformity of the field.

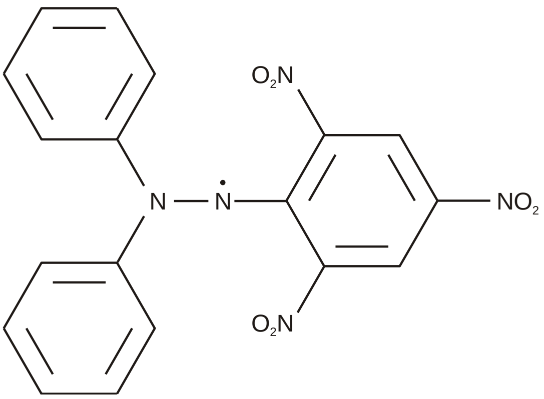

Fig. 2: Molecular structure of DPPH

The magnetic moment of an electron with purely spinrelated magnetism assumes discrete values in a magnetic field B:

(1) $E_{\mathrm{m}} = -g_{\mathrm{J}} \cdot \mu_{\mathrm{B}} \cdot m \cdot B, \quad m = -\frac{1}{2}, \frac{1}{2}$

$\mu_{\mathrm{B}} = 9{,}274 \cdot 10^{-24} \, \frac{\mathrm{J}}{\mathrm{T}}$: Bohr magneton

g_{J} = 2.0023: Landé g-factor

The interval between the two levels is therefore

(2) $\Delta E = g_{\mathrm{J}} \cdot \mu_{\mathrm{B}} \cdot B$

Resonance occurs when the frequency f of the alternating field being fed in meets the following condition:

(3) $h \cdot f = \Delta E$,

$h = 6.626 \cdot 10^{-34}$ Js: Planck's constant

In this experiment, electron spin resonance will be demonstrated in diphenyl-picrylhydrazyl (DPPH), an organic compound, the molecules of which include an unpaired electron. The basic magnetic field is generated inside a pair of Helmholtz coils and is moved between zero and a maximum value of B_{max} = 3.5 mT using a saw-tooth wave-form. Now it is possible to look for a frequency f, at which resonance absorption takes place at a distinct position along the saw-tooth curve, i.e. for a pre-selected magnetic field. Increasing the frequency shifts the resonance absorption toward larger magnetic fields.

LIST OF EQUIPMENT

1	ESR/NMR Basic Set @230V	1000638 (U188031-230)
or		
1	ESR/NMR Basic Set @115V	1000637 (U188031-115)
1	ESR Supplementary Set	1000640 (U188501)
1	PC Oscilloscope, 2x25 MHz	1020857 (U11830)
2	HF Patch Cord	1002746 (U11255)

SET-UP

- Set up the base unit and connect it to the control panel as described in the instruction manual for the ESR supplementary set 1000640.
- Connect the "SIGNAL OUT" output of the control panel to channel 1 of the PC oscilloscope, and the "FIELD OUT" output to channel 2.
- Set the following parameters on the PC oscilloscope:

Horizontal:	
Time base:	2 ms/div
Horizontal trigger position:	5.000 ms
Vertical:	
CH1:	
Voltage scale division:	1 V/div DC
Zero-point position:	−2.52 divs
CH2:	
Voltage scale division:	200 mV/div DC
Zero-point position:	−2.52 divs
Trigger:	
Single (not alternate)	
Source:	CH2
Mode:	Edge
Edge:	Rise
Threshold:	400 mV
TrigMode:	Auto

EXPERIMENT PROCEDURE

- On the control panel, set the smallest frequency at which a defined resonance absorption signal can be observed (approx. 37 MHz).
- Adjust the "SENSITIVITY" control so as to maximize the signal level.

At the optimal setting, the LED flickers faintly. If the LED shines brightly, the signal is overdriven.

- Read the resonance coil voltage U_{R} with the help of the cursor on the PC oscilloscope (Figures 3, 4). For this, select the "Cursor" submenu from the main menu, place a tick mark on the "Voltage" option under "Channel:", and select "CH2". Use the first cursor (Y1) for reading, and set the second cursor (Y2) to 0.000 mV. The second cursor then represents the zero point position −2.52 divs of CH1 and CH2.

Note:
After each parameter change on the PC oscilloscope, you must again check the "Voltage" option in the "Cursor" submenu and select "CH2".

- Repeat the measurement for various frequencies between 40 and 70 MHz in 5 MHz increments, and enter the respective, set frequencies as well as the measured resonance coil voltages in Table 1.

Note:
At frequencies greater than 45 MHz, the voltage scale division for CH1 must be adjusted from 1 V/div to 500 mV/div.

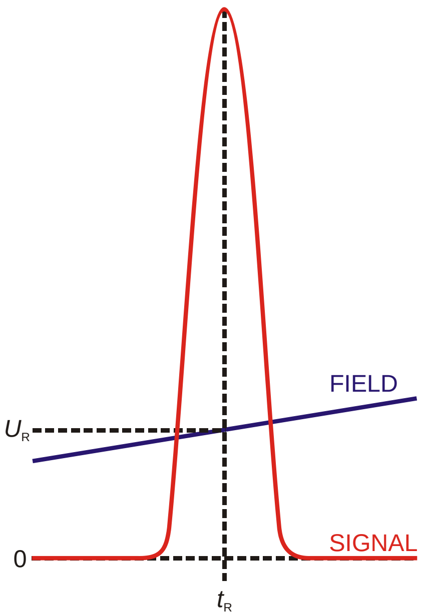

Fig. 3: Schematic sketch for reading the resonance coil voltage U_R from the oscillogram.

SAMPLE MEASUREMENT AND EVALUATION

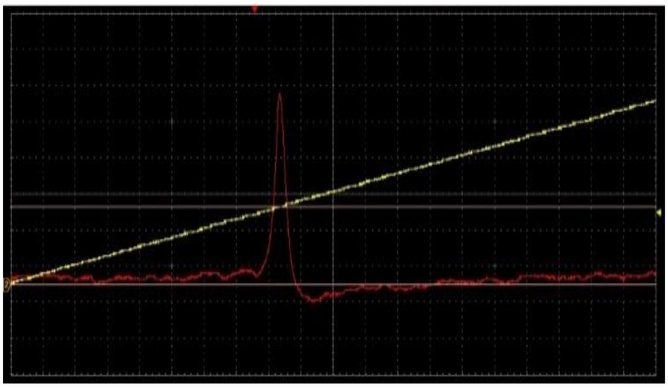

Fig. 4: Absorption signal (red) and the magnetic field trace over time (yellow) for electron spin resonance in DPPH.

Tab. 1: Set resonance frequencies f, resonance coil voltages U_R and resultant, calculated magnetic fields B.

f / MHz	U_R / V	B / mT
37.408	0.360	1.25
40.006	0.384	1.33
44.996	0.432	1.50
49.995	0.480	1.67
55.004	0.524	1.82
59.999	0.580	2.01
65.004	0.632	2.19
70.005	0.680	2.36

- From the resonance coil voltages U_R (Table 1), calculate the magnetic fields as follows:

  (5) $$B = 3.47\,\frac{\text{mT}}{\text{V}}\cdot U_R$$

  and enter the values in Table 1.

Obtained from (2) and (3) is the following relationship between the resonance frequency f and magnetic field B:

(6) $$f = g_J \cdot \frac{\mu_B}{h} \cdot B = a \cdot B\,.$$

The measured values therefore lie on a straight line which passes through the origin and whose slope 'a' can be used to determine the Landé factor.

- Plot the set resonance frequencies (Table 1) as a function of the magnetic fields calculated from the resonance coil voltages (Table 1), and accordingly form a straight line passing through the origin (Figure 5).
- Determine the Landé factor with the help of equation (6):

(7) $$g_J = a \cdot \frac{h}{\mu_B} = 30\cdot 10^9\,\frac{1}{\text{T}\cdot\text{s}} \cdot \frac{6.626\cdot 10^{-34}\ \text{J}\cdot\text{s}}{9.274\cdot 10^{-24}\ \frac{\text{J}}{\text{T}}} = 2.1\,.$$

Within its relative uncertainty of approximately 5%, the value concurs well with what is found in the literature.

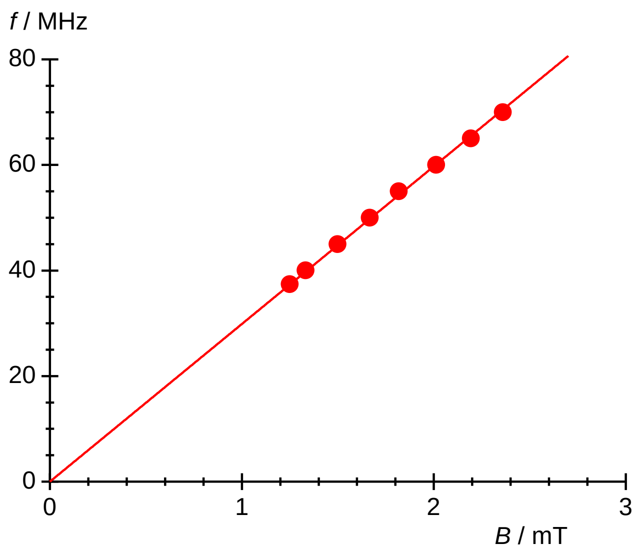

Fig. 5: Resonant frequency f as a function of the magnetic field B.