

## Charging and Discharging a Coil

### INVESTIGATION OF HOW THE CURRENT THROUGH A COIL CHANGES OVER TIME WHEN THE DC SUPPLY IS TURNED ON AND OFF

- Measure the current in a coil when a DC supply is turned on and when it is turned off.
- Determine the half-life period when a DC supply is turned on and when it is turned off.
- Investigate how the half-life depends on inductance and resistance.

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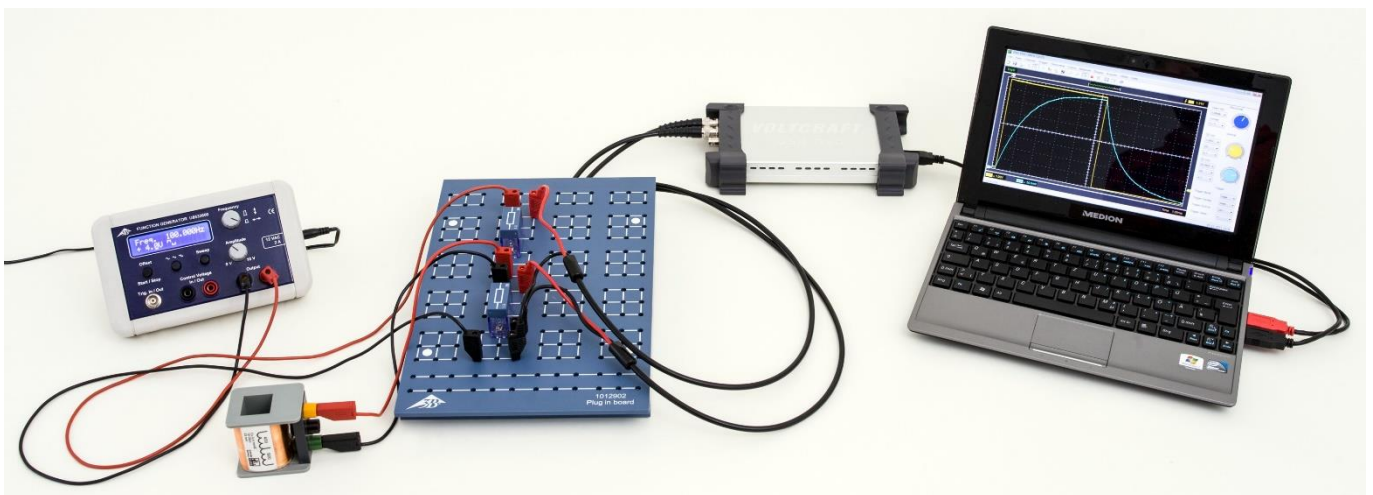


Fig. 1: Measurement set-up

### BASIC PRINCIPLES

The behaviour of a coil in a DC circuit changes as soon as the DC supply is turned on or off. The change in current is delayed by self-induction of the coil until it reaches its final value when turning on or zero when turning off. A plot of the coil current against time can be shown to be an exponential curve.

For a DC circuit featuring an inductance  $L$ , an ohmic resistance  $R$  and DC voltage  $U_0 = R \cdot I_0$ , the following applies when the supply is switched on:

$$(1) \quad I(t) = I_0 \cdot \left(1 - e^{-\frac{t \cdot \ln 2}{T_{1/2}}}\right)$$

The following applies when the power is supply off:

$$(2) \quad I(t) = I_0 \cdot e^{-\frac{t \cdot \ln 2}{T_{1/2}}}$$

with

$$(3) \quad T_{1/2} = \ln 2 \cdot \frac{L}{R}$$

$T_{1/2}$  is the half-life period, i.e. the current through the coil will halve within a time  $T_{1/2}$ . The same period elapses when the current drops from a half to a quarter and from a quarter to an eighth.

These aspects will be investigated in the experiment. How the coil current changes over time is recorded using a storage oscilloscope. The current is measured by means of the voltage drop across a resistor  $R_M$ . The current  $I_0$  has been selected such that a half, a quarter and an eighth of this current are easy to read off. In order to vary the ohmic resistance, various test resistors  $R_R$  will be connected together in series.

The ohmic resistance  $R$  is derived from the sum of the test resistor, the ohmic component of the coil resistance and that of the measurement resistor:

$$(4) \quad R = R_R + R_L + R_m$$

**LIST OF APPARATUS**

- |   |                                 |                        |
|---|---------------------------------|------------------------|
| 1 | Plug-In Board for Components    | 1012902 (U33250)       |
| 1 | Resistor 1 $\Omega$ , 2 W       | 1012903 (U333011)      |
| 1 | Resistor 10 $\Omega$ , 2 W      | 1012904 (U333012)      |
| 1 | Resistor 22 $\Omega$ , 2 W      | 1012907 (U333015)      |
| 1 | Resistor 47 $\Omega$ , 2 W      | 1012908 (U333016)      |
| 1 | Resistor 150 $\Omega$ , 2 W     | 1012911 (U333019)      |
| 1 | Set of 10 Jumpers               | 1012985 (U333093)      |
| 2 | Coil S with 1200 Taps           | 1001002 (U8498085)     |
| 1 | Function Generator FG 100 @230V | 1009957 (U8533600-230) |
- or
- |   |   |                        |
|---|---|------------------------|
| 1 | Function Generator FG 100 @115V                     | 1009956 (U8533600-115) |
| 1 | PC Oscilloscope 2x25 MHz                            | 1020857 (U11830)       |
| 2 | HF Patch Cord, BNC/4 mm Plug                        | 1002748 (U11257)       |
| 1 | Set of 15 Experiment Leads, 75 cm 1 mm <sup>2</sup> | 1002840 (U13800)       |

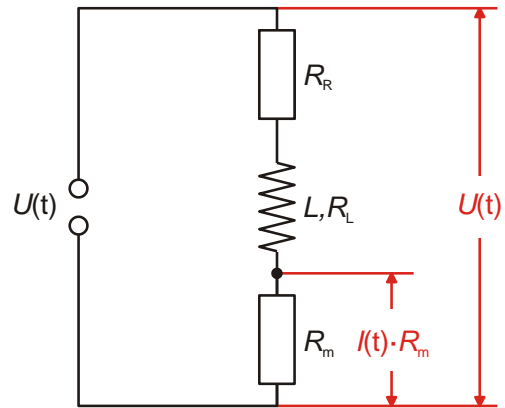


Fig. 3: Sketch of circuit

**EXPERIMENT SET-UP AND PROCEDURE**

- Set-up the apparatus as shown in Fig. 2.
- Assemble the circuit shown in Fig. 3 on the plug-in board.
- On the oscilloscope set the time base to 1 ms, the vertical deflection sensitivity to 1 V for channel 1 and 50 mV for channel 2. Set trigger mode to Edge, trigger sweep to Auto, trigger source to CH1 and trigger level to 522 mV.

**Half-life period when a DC supply voltage is switched on or off**

- Plug one of the 23 mH coils with 1200 windings and the measurement resistor  $R_m = 1 \Omega$  into the plug-in board as shown in Fig. 2 and Fig. 3. Initially plug in a jumper in place of one test resistor  $R_R$ .
- Set a frequency of 100 Hz and a square wave form on the function generator.
- Select the amplitude such that the height of the signal is 8 V peak to peak, which corresponds to  $\pm 4$  divisions when the setting is 1 V/division.
- Read off from the oscilloscope the times  $T_{1/2}$  it takes the inductor to discharge by half-way from voltages of 8 V down to 4 V, 4 V down to 2 V and 2 V down to 1 V after the DC voltage has been switched off, and enter the results into Table 1.

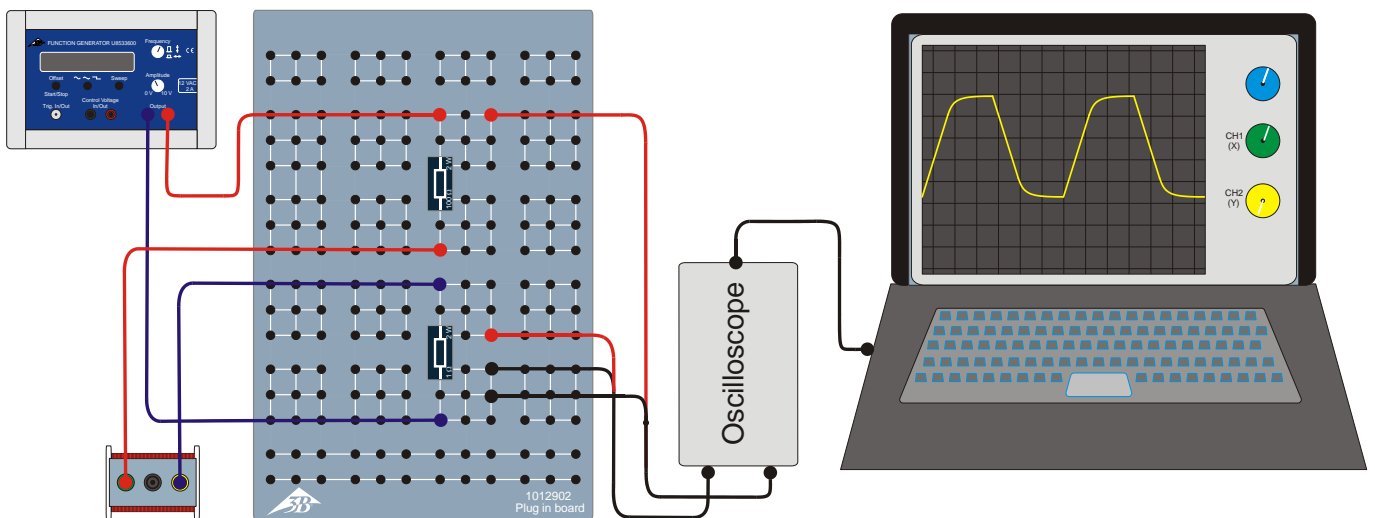


Fig. 2: Sketch of experiment set-up

- Read off from the oscilloscope the half-life periods  $T_{1/2}$  as the inductor charges after the DC voltage has been switched on for rises in voltage from 0 V to 4 V, 4 V to 6 V and 6 V to 7 V, and enter the values into Table 2.

Since the current  $I_0 = U_0 / R = U_m / R_m$ , where  $R_m = 1 \Omega$  flows through both the measurement resistor and the coil, the decreases and increases in voltage across the measurement resistor directly reflect the rises and falls in current through the inductor.

**Half-life periods with various resistors**

- Use one 23 mH coil with 1200 windings.
- In order, plug in the jumper ( $R_R = 0 \Omega$ ), then the various test resistors  $R_R = 10, 22, 47$  and  $150 \Omega$  into the circuit.
- For each of these test resistances  $R_R$ , read the half-life period  $T_{1/2}$  from the oscilloscope as the voltage discharges after the DC supply has been switched off and enter the value into Table 3. Optionally, you can determine the half-lives during charging when the DC voltage is switched on as well. In each case, derive an average for the half-life period.

**Half-life periods with various inductors**

- Use a test resistor of  $R_R = 47 \Omega$ .
- One after the other, set up circuits with inductances of  $L = 23, 46$  and  $11.5$  mH by connecting the two 23 mH coils with 1200 windings in series or parallel in such a way as to achieve the above values.
- For each of these inductances  $L$ , read the half-life period  $T_{1/2}$  from the oscilloscope as the voltage discharges after the DC supply has been switched off and enter the value into Table 4. Optionally, you can determine the half-lives during charging when the DC voltage is switched on as well. In each case, derive an average for the half-life period.

**SAMPLE MEASUREMENTS**

Fig. 4 shows an example oscilloscope trace for charging and discharging of a coil after a DC voltage has been switched on across it and then switched off again. The yellow curve (CH1) shows how the voltage changes with time across the full ohmic resistance (see equation (4)), while the blue curve (CH2) shows how the current changes in the coil.

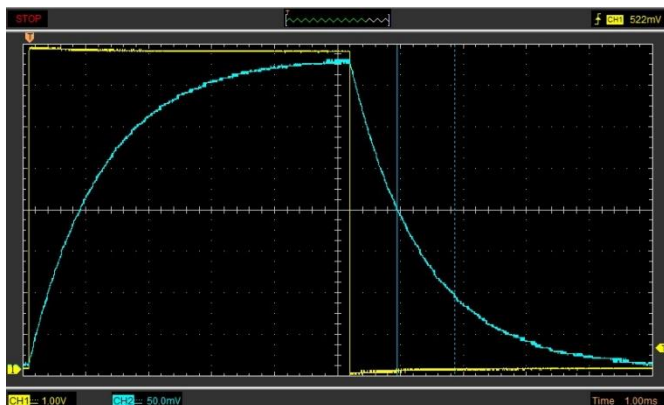


Fig. 4: Oscilloscope traces of current through a coil (blue curve) after switching DC voltage on and off.

Table 1: Half-life periods  $T_{1/2}$  for various voltage drops ( $R_R = 0 \Omega, R_m = 1 \Omega, R_L = 19 \Omega, L = 23$  mH).

$T_{1/2}(8\text{ V} \rightarrow 4\text{ V})$	$T_{1/2}(4\text{ V} \rightarrow 2\text{ V})$	$T_{1/2}(2\text{ V} \rightarrow 1\text{ V})$
0.816 ms	0.788 ms	0.830 ms

Table 2: Half-life periods  $T_{1/2}$  for various voltage rises ( $R_R = 0 \Omega, R_m = 1 \Omega, R_L = 19 \Omega, L = 23$  mH).

$T_{1/2}(0\text{ V} \rightarrow 4\text{ V})$	$T_{1/2}(4\text{ V} \rightarrow 6\text{ V})$	$T_{1/2}(6\text{ V} \rightarrow 7\text{ V})$
0.817 ms	0.835 ms	0.840 ms

Table 3: Half-life periods  $T_{1/2}$  for various test re-sistances  $R_R$  ( $R_m = 1 \Omega, R_L = 19 \Omega, L = 23$  mH).

$R_R / \Omega$	0	10	22	47	150
$R / \Omega$	20	30	42	67	170
$T_{1/2} / \text{ms}$	0.83	0.44	0.38	0.25	0.10

Table 4: Half-life periods  $T_{1/2}$  for various inductances  $L$  ( $R_R = 47 \Omega, R_m = 1 \Omega$ ).

$L / \text{mH}$	$R_L / \Omega$	$R / \Omega$	$T_{1/2} / \text{ms}$
23.0	19.0	67.0	0.25
46.0	38.0	86.0	0.41
11.5	9.5	57.5	0.14

**EVALUATION**

**Half-life period when a DC supply voltage is switched on or off**

The agreement of the values determined for half-life periods in various sections of the curves after a DC voltage has been switched on and off across a coil (Table 1 and Table 2) confirms the expected exponential relationship, see equations (1) and (2).

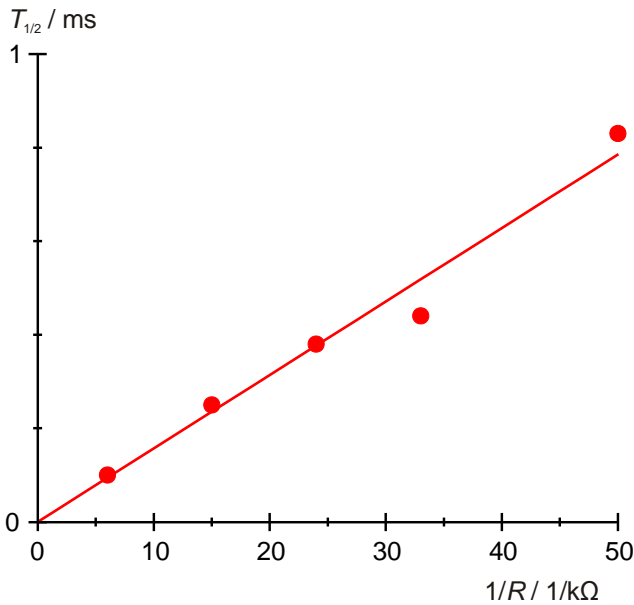


Fig. 5: Half-life  $T_{1/2}$  as a function of the inverse of resistance  $R$ .

Table 5: Half-life periods  $T_{1/2}$  for quotients  $L/R$  calculated from values in Tab. 3 and 4.

$L/R$ / ms	$T_{1/2}$ / ms
0.14	0.10
0.20	0.14
0.34	0.25
0.55	0.38
0.53	0.41
0.77	0.44

**Half-life periods with various resistors**

- Plot the half-life periods  $T_{1/2}$  from Table 3 against the inverse of the ohmic resistance values  $R$  and fit a straight line through the origin (Fig. 5).
- To check equation (3), determine the inductance  $L$  from the measured gradient  $m_L$ .

$$(5) \quad T_{1/2} = \frac{m_L}{R} \quad \text{with} \quad m_L = \ln 2 \cdot L$$

$$\Rightarrow L = \frac{m_L}{\ln 2} = \frac{15.7}{\ln 2} = 22.5 \text{ mH.}$$

The value obtained by measurement is well in agreement with the nominal inductance value of  $L = 23$  mH.

**Half-life periods with various inductors**

Since implementing various inductance values by shuffling inductors also changes the ohmic resistance, we will check how the half-life period depends on the ratio  $L/R$ .

- Divide the inductance value  $L = 23$  mH by the ohmic resistances  $R$  in Table 3 and the inductance value from Table 4 by the corresponding ohmic resistance values  $R$  from that table and enter the quotients  $L/R$  alongside their corresponding half-lives from Tables 3 and 4 in Table 5.
- Plot the half-life periods  $T_{1/2}$  from Table 5 against the quotients  $L/R$  on a graph and fit a straight line through the origin (Fig. 6).

- To check equation (3) with the measured gradient  $m$ , compare it to the expected coefficient of proportionality  $\ln 2$ .

$$(6) \quad T_{1/2} = m \cdot \frac{L}{R} \quad \text{with} \quad m = \ln 2$$

The measured gradient  $m = 0.66$  is well in agreement with the theoretical value  $\ln 2 = 0.69$ .

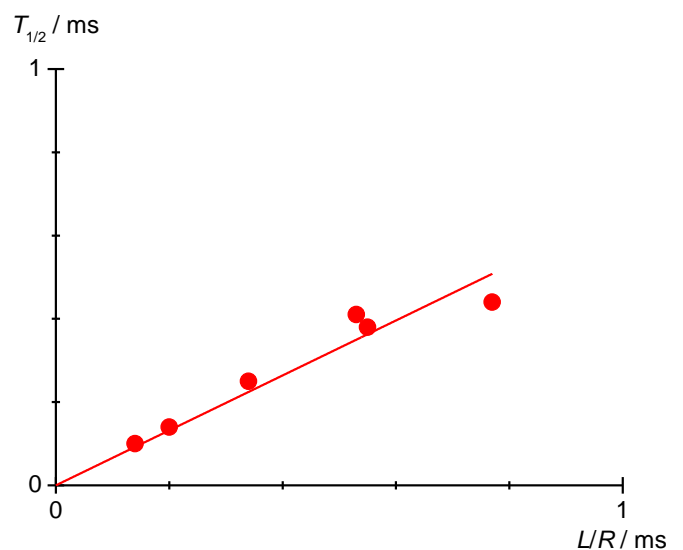


Fig. 6: Half-life  $T_{1/2}$  as a function of  $L/R$ .