MEASUREMENT OF THE MAGNETIC FIELDS

OBJECT

1. To measure the magnetic induction on the axis of three closely packed solenoids inside and outside them. To plot the obtained dependence of the magnetic induction inside the solenoids and the theoretical dependence.
2. On the base of experimental and theoretical results discuss the region of the validity of the formulae 1 for the magnetic induction B_s inside the solenoid.
3. To measure the magnetic induction on the axis of the Helmholtz coils for the distances *a* between them $a = R/2$, R, $2R$ (R is the radius of the coils). Plot the graph of the obtained results and compare it with the theoretical results.
4. To evaluate the error of measurements.

THEORY

1. Magnetic induction on the axis of the closely packed solenoid.

The magnetic induction B_s inside the closely packed solenoid of the length L and of the number of turns N is given by the expression:

$$B_s = \mu_0 I n \qquad (1)$$

In this expression μ_0 is the permeability of a vacuum, I is the current and $n = N/L$ is the density of turns. (The formulae 1 is valid for infinitely long solenoid. The calculation of the magnetic induction inside the solenoid can be found in Physics I – Seminars, M. Murla, S. Pekárek, CTU Prague, 1995.)
The photograph of solenoids is shown in Figure 1.

2. Magnetic induction on the axis of the Helmholtz coils.

The magnetic induction B_H in the middle of the Helmholtz coils is given by the expression:

$$B_H = 0.71 \frac{\mu_0 I N}{R} \qquad (2)$$

In this expression μ_0 is the permeability of a vacuum, I is the current, N is the number of turns and R is the radius of the coils.
The photograph of the Helmholtz coils is shown in Figure 1.
The magnetic induction is measured with the Hall probe, which utilizes the Hall effect.

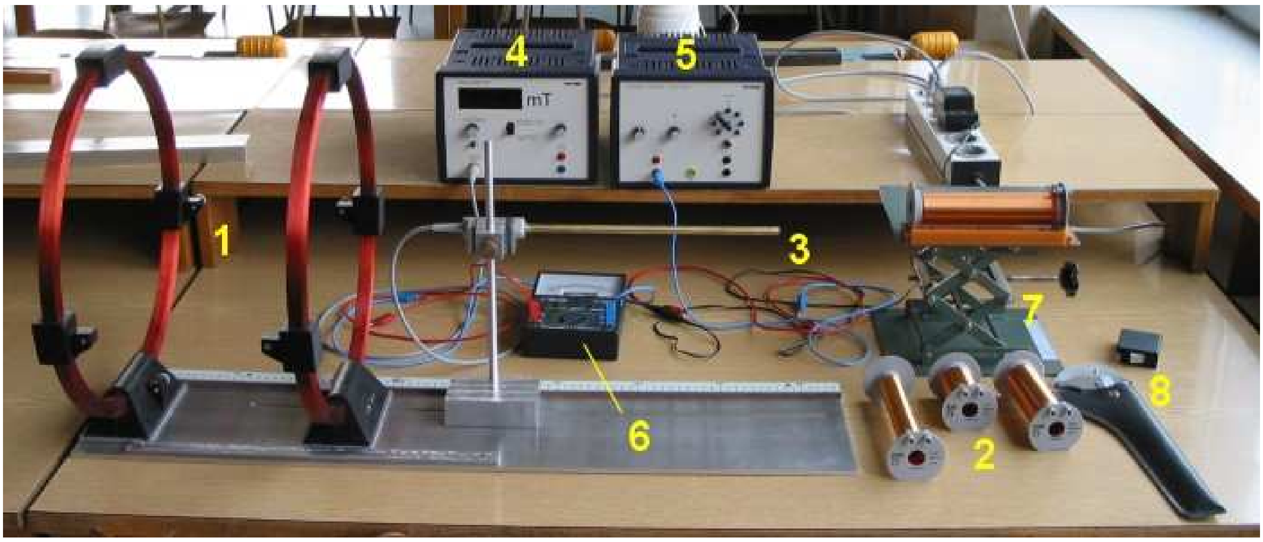

Figure 1. Experimental arrangement.
1-Helmholtz coils; 2-Solenoids; 3-Hall probe; 4-Teslameter; 5-Power supply unit; 6-Ammeter;

7-Movable table; 8-Calliper and meter.

Front panel of the Teslameter and power supply unit is shown in Figure 2.

Figure 2. Teslameter and power supply unit.

1. Adjustement of the measuring range; 2.Measurement of the direct or variable magnetic field; 3. Zero adjustement – „fie“; 4. Zero adjustement – „rough“; 5. Hall probe conector; 6.Voltage adjustement; 7. Current adjustement; 8. Output terminals.

The Hall effect

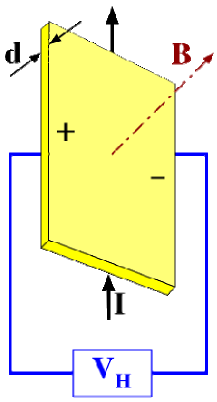

Figure 3. Hall effect.

The Hall effect is the production of a voltage difference (the Hall voltage) $\mathbf{V_H}$ across an electrical conductor (semiconductor), transverse to an electric current density in the conductor and a magnetic field **B** perpendicular to the current. The electric current constitutes motion of the charge carriers. These charge carriers are affected by the Lorentz force. The result is a charge separation, with a build up of either positive or negative charges on the left or on the right side of the plate.

The Hall coefficient is defined as the ratio of the induced electric field to the product of the current density and the applied magnetic field. It is a characteristic of the material from which the conductor is made, as its value depends on the type, number, and properties of the charge carriers that constitute the current.

Hall effect sensor - Hall probe

A Hall effect sensor is a transducer that varies its output voltage in response to changes in magnetic field. In its simplest form, the sensor operates as an analogue transducer, directly returning a voltage.

A Hall probe contains an indium compound crystal such as indium antimonide, mounted on an aluminum backing plate, and encapsulated in the probe head. Connecting leads from the crystal are brought down through the handle to the circuit box.

When the Hall probe is held so that the magnetic field lines are passing at right angles through the sensor of the probe, the meter gives a reading of the value of magnetic induction. The crystal measures 5 mm square. The probe handle, being made of a non-ferrous material, has no disturbing effect on the field. For a solenoid the Hall probe is placed in the center.

Warning: Manipulate with the Hall probe with extreme care, it is very fragile instrument.

PROCEDURE

Part A. Measurement of the magnetic induction inside the solenoids:
Connect the solenoid, teslameter, power supply unit and ammeter according to the scheme shown in Fig. 4.

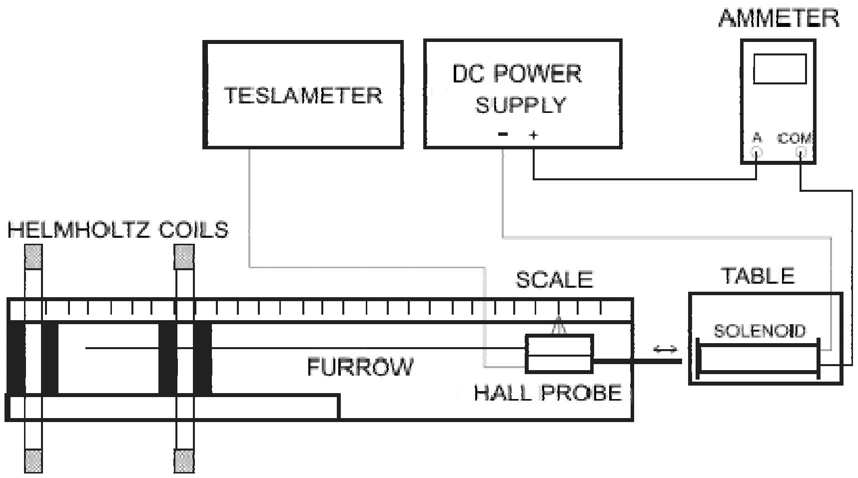

Figure 4. Experimental scheme for the measurement of the magnetic induction inside the solenoids.

1. Place the first solenoid on the movable table so that its sides fit into the openings on the table.
2. Measure the length of the first solenoid. Measure the length of the solenoid occupied by the turns. Measure the distance of the right end of the solenoid from the right end of the solenoid occupied by the turns.
3. For the voltage 17 V on the power supply adjust with the help of digital multimeter (ammeter) the current through the solenoid 1 A.
4. Place the Hall probe into the holder and conect it to the Teslameter. For the measurement choose the measurement of the direct fields (GLEICHFELD) and measuring range 20. Finally with the help of the „Zero adjustement“ potentiometer adjust the zero value of magnetic induction for the case when the power supply for solenoids is switched off. If it is impossible to adjust the zero value of the magnetic induction, use the Zero adjustement – „rough“; (see Fig.2). The zero value of magnetic induction adjustement must be checked before starting measurement of each solenoid.
5. Place the Hall probe into the axis of the solenoid and through the whole solenoid on the end of the solenoid opposite to the Hall probe hoolder.
6. Read the values of magnetic induction on teslameter for particular positions of the Hall probe along the axis of the solenoid. Choose sufficient number of points to plot the dependence of magnetic induction on the axis of the solenoid along its length. Read the x-coordinate of the Hall probe on the scale on the table. Notice that the length of the solenoid is not identical with the length of the solenoid occupied by the turns.
7. Plot the obtained results into the graph of magnetic induction versus the distance *x* (length of the solenoid). Into the same graph plot the theoretical results and evaluate the region of the validity of the formulae 1.
8. Repeat the same measurement with the second and the third solenoid.

Part B. Measurement of the magnetic induction on the axis of the Helmholtz coils
Parameters of the Helmholtz coils: Number of turns 154, radius R = 200 mm.

1. Adjust the first distance between the Helmholtz coils to a = $R/2$. For this distance, that is a=100 mm, the white triangle pointer should read on the scale the value 100.
2. With the help of holder place the Hall probe into the center of the right coil. The pointer on the Hall probe holder should read on the scale the value a + 300, tj. 400, 500 nebo 700 mm.
3. Connect the coils, teslameter, power supply unit and ammeter according to the scheme shown in Fig.5. Check the zero value of magnetic induction before starting measurement for each distance of the Helmholtz coils. Adjust the current through the coils to 3 A.
4. Measure the magnetic induction on the axis of the Helmoltz coils as a function of the position x. The values of x read with the pointer on the probe on the scale.
5. Plot the graph of experimental points and the theoretical points.
6. Repeat the same measurements for the distances between the coils 200 (R) nebo 400 (2R) mm.

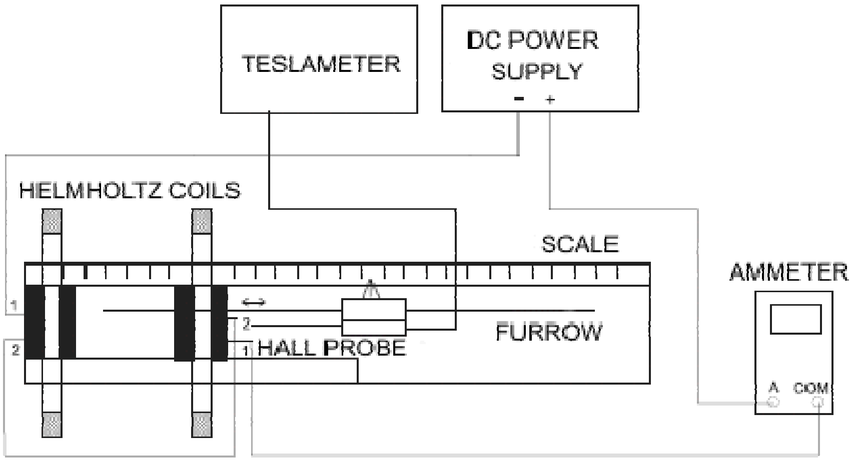

Figure 5. Experimental scheme for the measurement of the magnetic induction on the axis of the Helmholtz coils.

SEMESTER WORK INSTRUCTIONS

The program should have two functions.
1) to calculate and draw the dependence of the magnetic induction on the position along the axis of the Helmholtz coils or the solenoid.
2) to calculate magnetic induction in any point in 3D space around the Helmholtz coils or the solenoid.

Variable input parameters for the solenoid: electric current, diameter of the solenoid, length of the solenoid, number of threads

Variable input parameters for the Helmholtz coils: electric current, distance between both coils, diameter of each coil, number of threads