Measuring the magnetic field for a straight conductor and on circular conductor loops

Objects of the experiments

- Measuring the magnetic field of a straight conductor and of circular conductor loops as a function of the current.
- Measuring the magnetic field of a straight conductor as a function of the distance from the axis of the conductor.
- Measuring the magnetic field of circular conductor loops as a function of the loop radius and the distance from the loop.

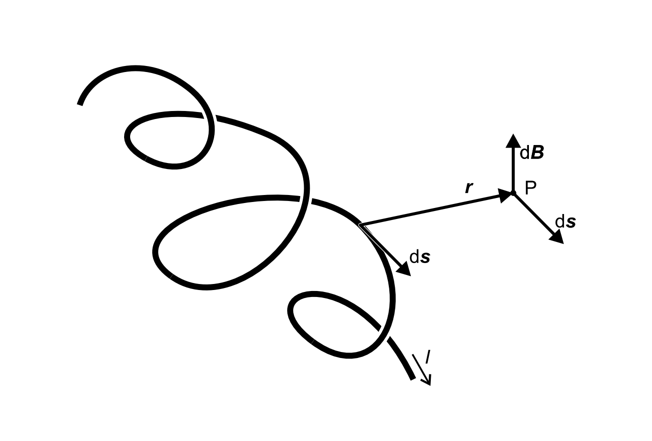
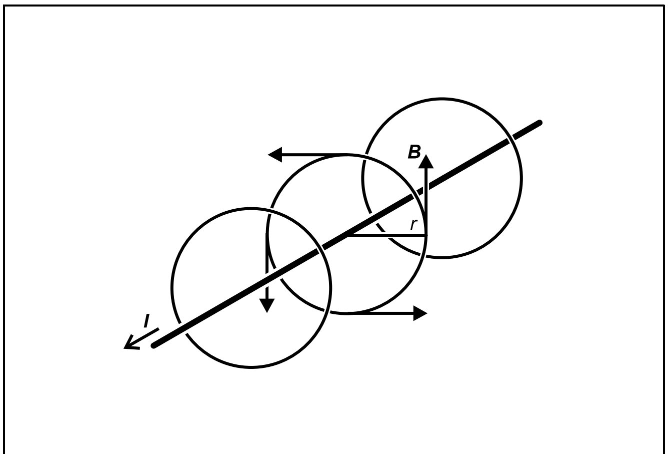


Fig. 1 Calculating of the magnetic field of a current-carrying conductor by integrating over the conductor.

Fig. 2 Magnetic field of an infinitely long wire.



Principles

According to *Biot-Savart's* law, the magnetic field ***B*** at a point P for a conductor traversed by the current *I* is made up of the contributions

$$\mathrm{d}\boldsymbol{B} = \frac{\mu_0}{4\pi} \cdot \frac{I}{r^2} \cdot \mathrm{d}\boldsymbol{s} \times \frac{\boldsymbol{r}}{r} \qquad \text{(I)}$$

$\mu_0 = 4\pi \cdot 10^{-7} \frac{\mathrm{Vs}}{\mathrm{Am}}$: permeability of free space

of the infinitesimal parts of the conductor, the length and direction of which are described by the vector d***s***. The position vector from the part of the conductor under consideration to the point P is given by ***r*** (see Fig. 1).

Calculating the total magnetic field thus means evaluating an integral. Analytic solutions can be given only for conductors with certain symmetries. The magnetic field of an infinitely long wire, for example, is

$$B = \frac{\mu_0}{4\pi} \cdot I \cdot \frac{2}{r} \qquad \text{(II)}$$

at a distance *r* from the axis, and the field lines are concentric around the cylinder axis (see Fig. 2).

0110-Kem/Sel

Apparatus

1 set of 4 current conductors	516 235
1 teslameter	516 62
1 axial B-probe	516 61
1 tangential B-probe	516 60
1 multicore cable, 6-pole	501 16
1 high current power supply	521 55
1 small optical bench	460 43
1 holder for plug-in elements	460 21
2 Leybold multiclamps	301 01
1 stand base, V-shape, 28 cm	300 01
1 set of two-way plug adapters	501 644
Connecting leads, Ø 2.5 mm^2	

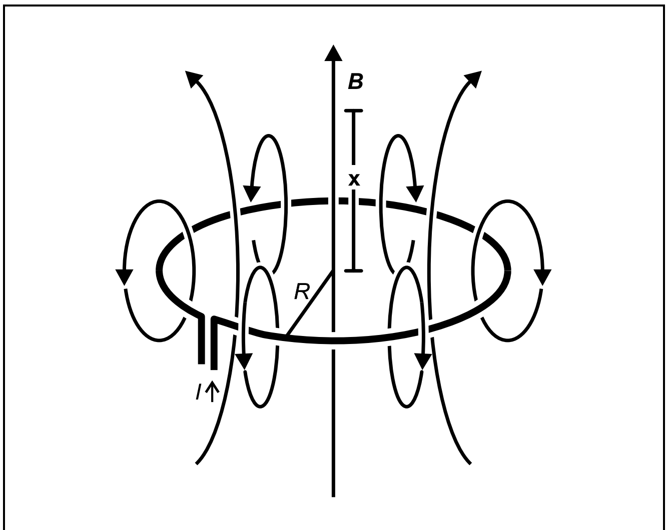
The magnetic field of a circular conductor loop with the radius *R* is

$$B = \frac{\mu_0}{4\pi} \cdot I \cdot 2\pi \cdot \frac{R^2}{\left(R^2 + x^2\right)^{\frac{3}{2}}} \qquad \text{(III)}$$

at a distance *x* on the axis through the centre of the loop. Its field lines are parallel to the axis (see Fig. 3).

In this experiment, the magnetic field of the above-mentioned conductors is measured by means of an axial or a tangential B-probe respectively. The Hall sensors of the B-probes, which are particularly thin, are sensitive to field components perpendicular to their surface. Therefore, not only the strength of the magnetic field can be determined, but also its direction. At the straight conductor, the dependence of the magnetic flux density *B* on the distance *r* is studied, at the circular conductor loops the dependence on the space coordinate *x*. Moreover, the proportionality between the magnetic induction *B* and the current *I* is verified.

Fig. 3 Magnetic field of a circular conductor loop.



Setup and carrying out the experiment

a) Magnetic field of a straight conductor:

The experimental setup is illustrated in Fig. 4.

– Set the small optical bench up in the stand base, and align it horizontally.
– Mount the holder for plug-in elements **(a)** with a Leybold multiclamp.
– Attach the holder for the straight conductor **(b_1)**, clamp the straight conductor, and connect it to the high current power supply.
– Connect the tangential B-probe to the teslameter, and adjust the zero of the teslameter (see instruction sheet of the teslameter).
– Next mount the tangential B-probe in a Leybold multiclamp with the left edge of the multiclamp lying at the scale mark 50.0 cm. Align the B-probe with the middle of the straight conductor in height.
– Move the straight conductor towards the Hall sensor **(c_1)** so that it almost touches the sensor (distance *s* = 0).
– Increase the current *I* from 0 to 20 A in steps of 2 A. Each time measure the magnetic field *B*, and take the measured values down.
– At *I* = 20 A, move the B-probe to the right step by step, measure the magnetic field *B* as a function of the distance *s*, and take the measured values down.

b) Magnetic field of circular conductor loops:

The experimental setup is illustrated in Fig. 5.

– Replace the holder for the straight conductor with the adapter for conductor loops **(b_2)**, and attach the 40 mm conductor loop.
– Connect the conductor loop by plugging connecting leads into the sockets of the holder for plug-in elements **(a)**.
– Connect the axial B-probe to the teslameter, and adjust the zero of the teslameter (see instruction sheet of the teslameter).
– Next mount the axial B-probe in a Leybold multiclamp with the left edge of the multiclamp lying at the scale mark 70.0 cm. Align the B-probe towards the centre of the conductor loop.
– Align the conductor loop as precisely as possible with the Hall sensor **(c_2)**.
– Increase the current *I* from 0 to 20 A in steps of 2 A. Each time measure the magnetic field *B*, and take the measured values down.
– At *I* = 20 A, move the B-probe to the right and to the left step by step, measure the magnetic field *B* as a function of the space coordinate *x*, and take the measured values down.
– Replace the 40 mm conductor loop with the 80 mm conductor loop and then with the 120 mm conductor loop. In both cases measure the magnetic field as a function of the space coordinate *x*.

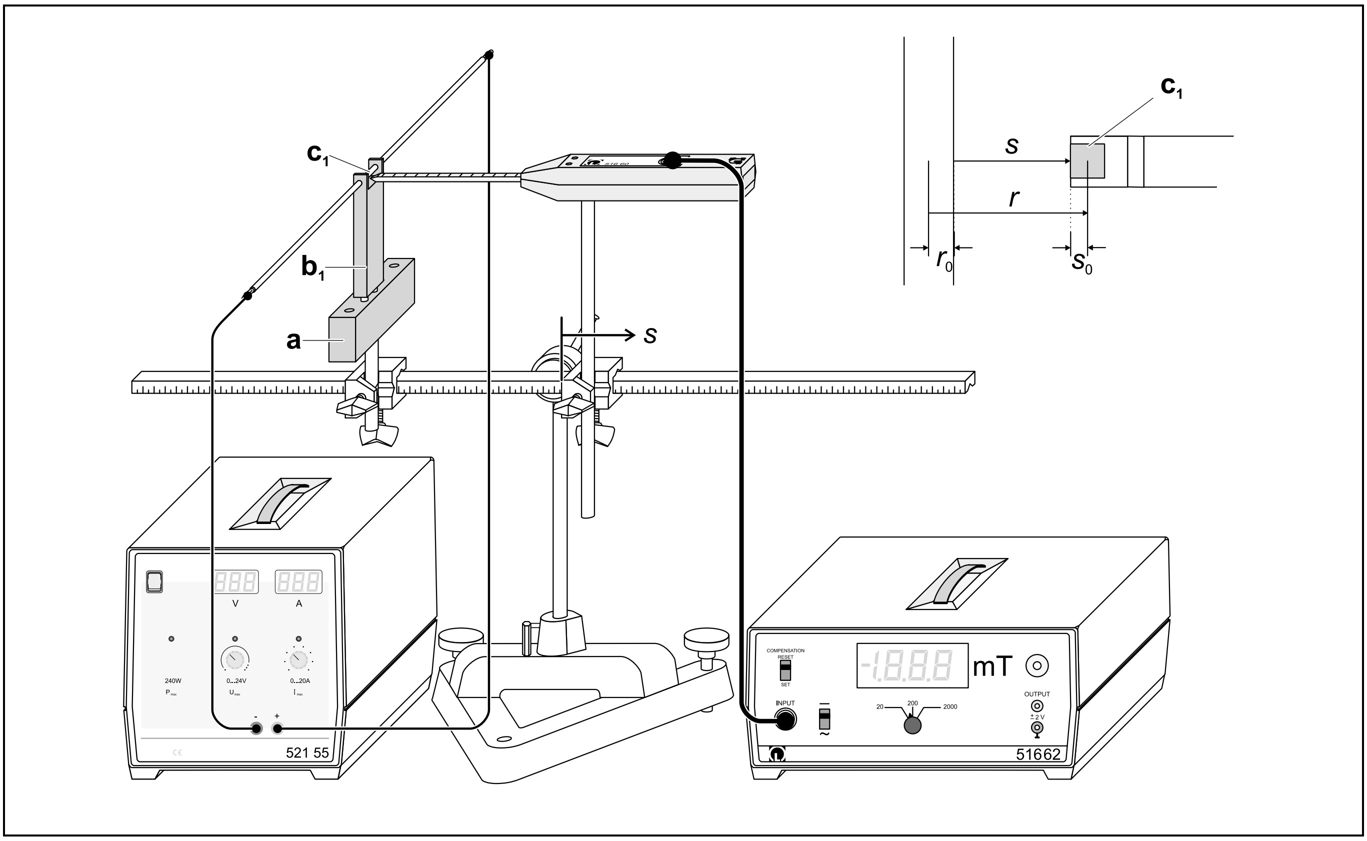
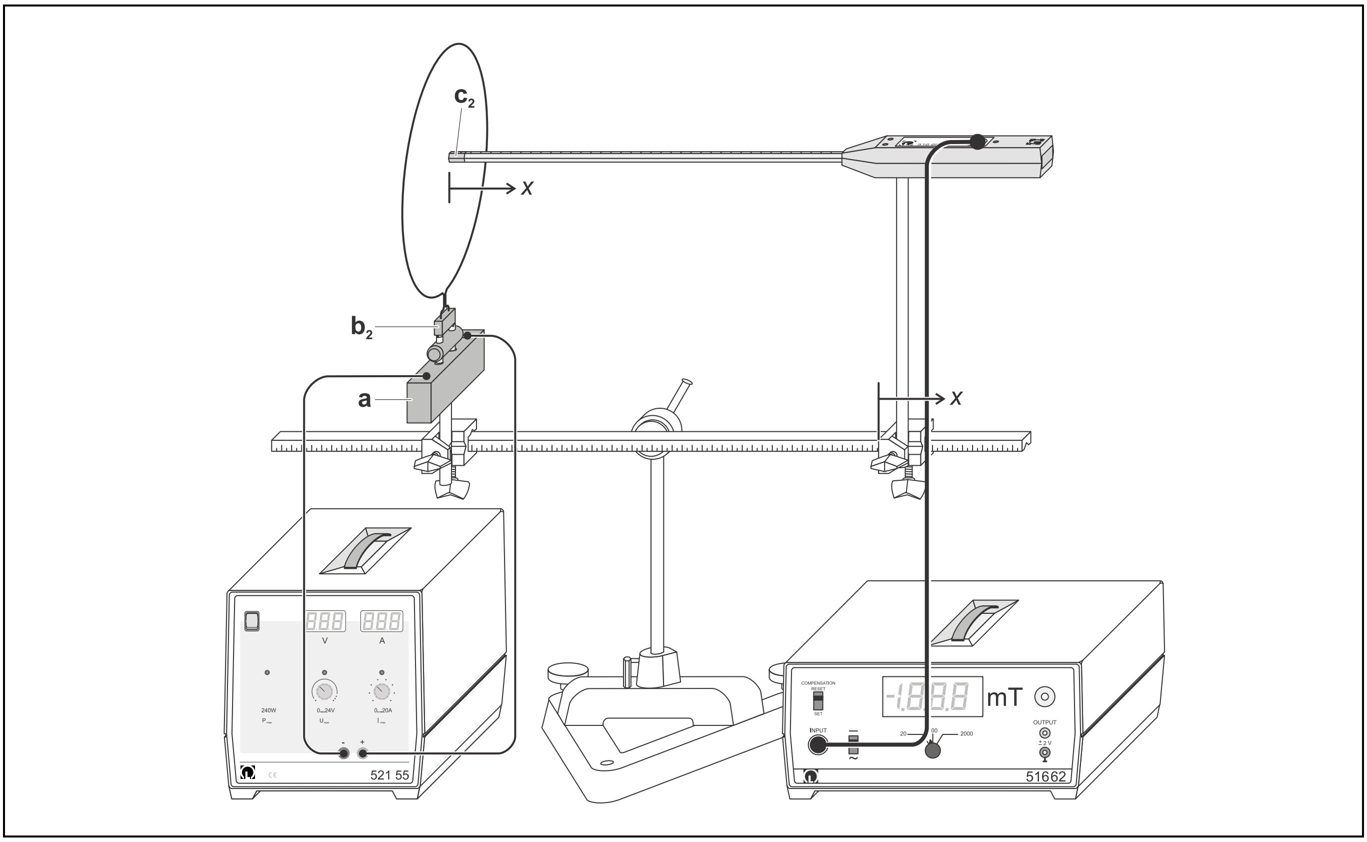


Fig. 4 Experimental setup for measuring the magnetic field at a straight conductor

Fig. 5 Experimental setup for measuring the magnetic field at circular conductor loops



Measuring example

a) Magnetic field of a straight conductor:

Table 1: The magnetic field *B* of the straight conductor as a function of the current *I* (distance s = 0)

$\frac{I}{A}$	$\frac{B}{mT}$
0	0.00
2	0.13
4	0.27
6	0.40
8	0.51
10	0.64
12	0.76
14	0.91
16	1.025
18	1.15
20	1.28

Table 2: The magnetic field *B* of the straight conductor as a function of the distance *s* between the surface of the conductor and the B-probe (current *I* = 20 A)

$\frac{s}{mm}$	$\frac{B}{mT}$
0	1.28
1	0.97
2	0.77
3	0.64
4	0.55
5	0.48
6	0.43
7	0.395
8	0.35
9	0.33
10	0.31
15	0.21
20	0.17
25	0.14
30	0.11
40	0.085

b) Magnetic field of circular conductor loops:

Table 3: The magnetic field *B* of the 40 mm conductor loop as a function of the current *I*

$\frac{I}{A}$	$\frac{B}{mT}$
0	0
2	0.07
4	0.13
6	0.19
8	0.26
10	0.32
12	0.38
14	0.45
16	0.51
18	0.58
20	0.64

Table 4: The magnetic field *B* of the conductor loops as a function of the distance *x*

$\frac{x}{mm}$	$\frac{B}{mT}$	$\frac{x}{mm}$	$\frac{B}{mT}$	$\frac{x}{mm}$	$\frac{B}{mT}$
2*R* = 40 mm		2*R* = 80 mm		2*R* = 120 mm	
–10	0.005	–10	0.015		
–7.5	0.015	–9	0.02		
–5	0.035	–8	0.03		
–4	0.06	–7	0.04	–9	0.04
–3	0.11	–6	0.05	–7.5	0.06
–2.5	0.14	–5	0.08	–6	0.08
–2	0.21	–4	0.11	–4.5	0.11
–1.5	0.33	–3	0.16	–3	0.15
–1	0.45	–2	0.23	–1.5	0.19
–0.5	0.58	–1	0.29	0	0.21
0	0.64	0	0.32	1.5	0.19
0.5	0.58	1	0.3	3	0.15
1	0.46	2	0.24	4.5	0.11
1.5	0.32	3	0.17	6	0.07
2	0.22	4	0.11	7.5	0.05
2.5	0.15	5	0.08	9	0.03
3	0.1	6	0.05		
4	0.05	7	0.04		
5	0.035	8	0.025		
7.5	0.01	9	0.02		
10	0.005	10	0.015		

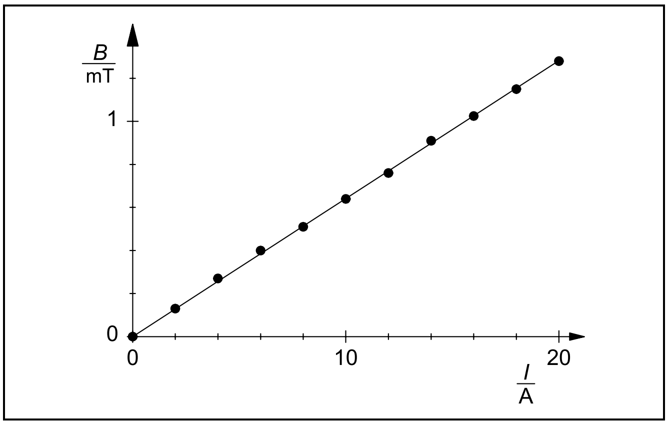


Fig. 6 The magnetic field *B* of the straight conductor as a function of the current *I*

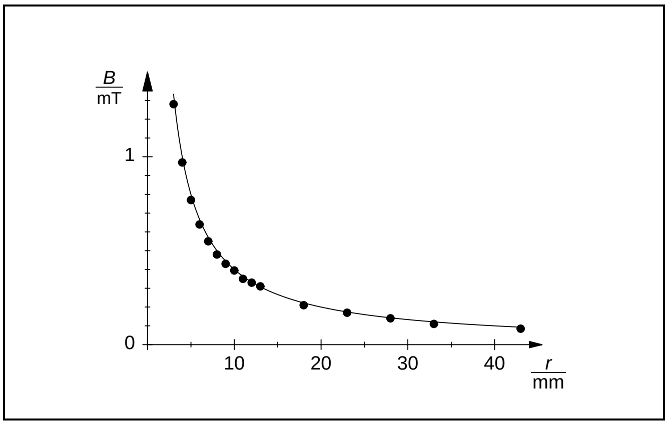


Fig. 7 The magnetic field *B* of the straight conductor as a function of the distance *r* from the axis of the conductor

Evaluation and results

a) Magnetic field of a straight conductor:

In Fig. 6, the dependence of the magnetic field *B* on the current *I* is shown graphically. Within the accuracy of measurement, the measured values (cf. Table 1) lie on the straight line through the origin drawn in the graph, that is, the magnetic field *B* is proportional to the current *I*.

Fig. 7 is a plot of the measured values from Table 2. The fact that the distance *s* between the surface of the conductor and the edge of the B-probe given in the table differs from the distance *r* from the axis of the wire entering in Eq. (I) has been taken into account. The difference *r* –*s* = 3 mm is the sum of the radius r_0 = 2 mm of the straight conductor and the distance s_0 = 1 mm between the edge of the B-probe and the centre of the Hall sensor (see Fig. 4). The curve drawn in Fig. 4 has been calculated according to Eq. (I) for *I* = 20 A. In the representation of Fig. 8, this curve corresponds to a straight line through the origin.

b) Magnetic field of circular conductor loops:

Fig. 9 shows the dependence of the magnetic field *B* of a circular conductor loop on the current *I*. In this case too, the agreement between the measured values (cf. Table 3) and the straight line through the origin drawn in the graph confirms the proportionality between the magnetic field *B* and the current *I*.

In Fig. 10, the dependence of the magnetic field *B* on the space coordinate *x* is shown for the three circular conductor loops. The curves drawn in the graph have been calculated according to Eq. (II) with the current *I* = 20 A.

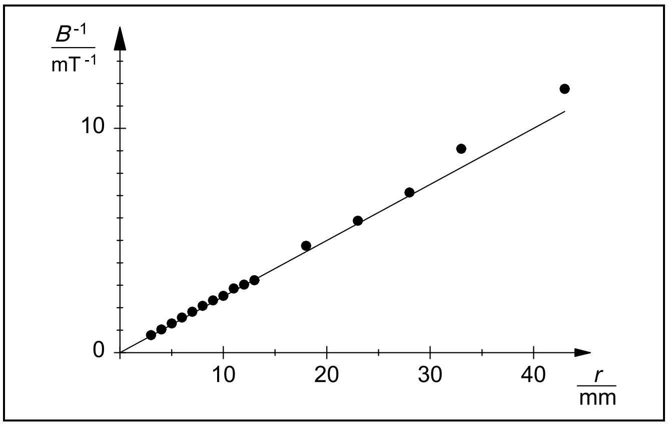


Fig. 8 The magnetic field *B* of the straight conductor in the representation 1/B = *f*(*r*)

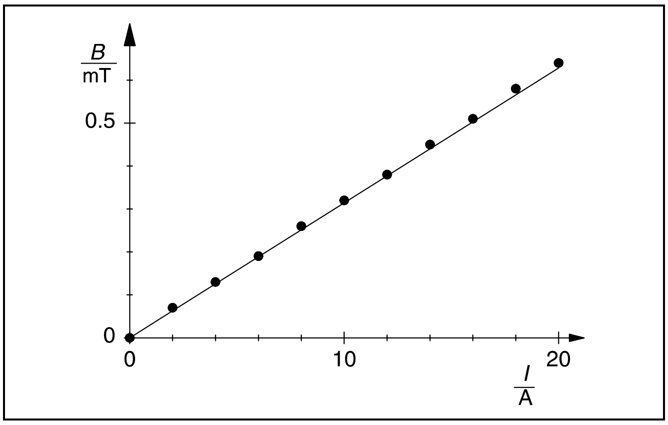


Fig. 9 The magnetic field B of a circular conductor loop (40 mm diameter) as a function of the current *I*

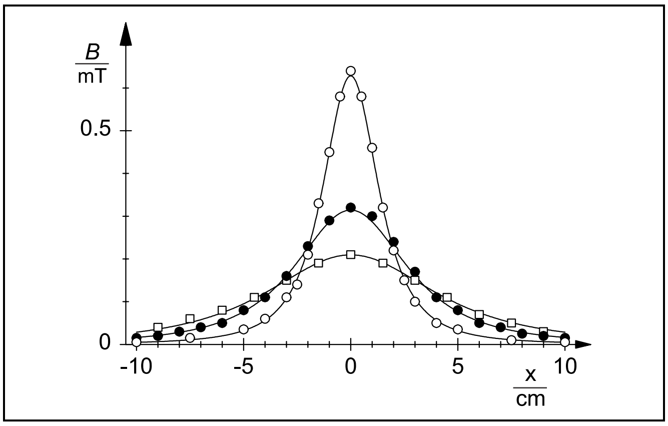


Fig. 10 The magnetic field B of circular conductor loops with radius *R* as a function of the space coordinate *x*
(◯) *R* = 60 mm, (●) *R* = 40 mm, (☐) *R* = 20 mm

© by LD DIDACTIC GmbH
Printed in the Federal Republic of Germany
Technical alterations reserved