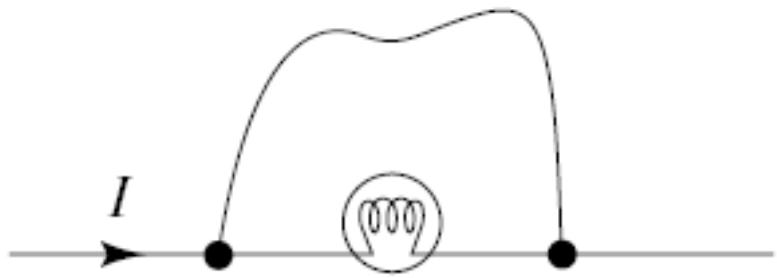
Consider two identical resistors wired in series (one behind the other). If there is an electric current through the combination, the current in the second resistor is

1. equal to
2. half
3. smaller than, but not necessarily half

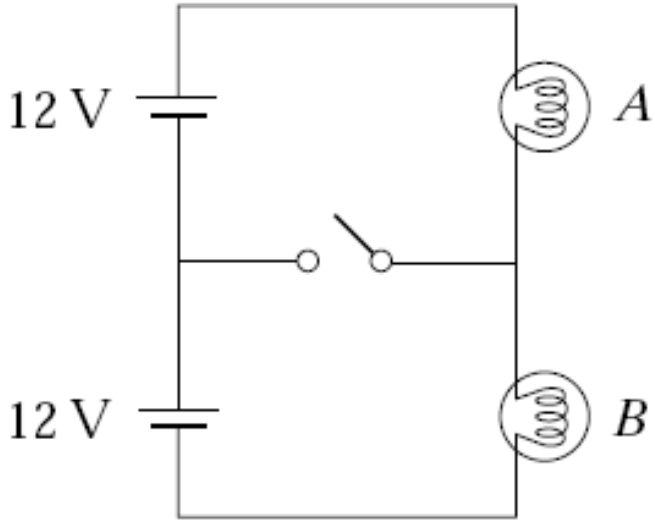
the current through the first resistor.

Charge flows through a light bulb. Suppose a wire is connected across the bulb as shown. When the wire is connected,



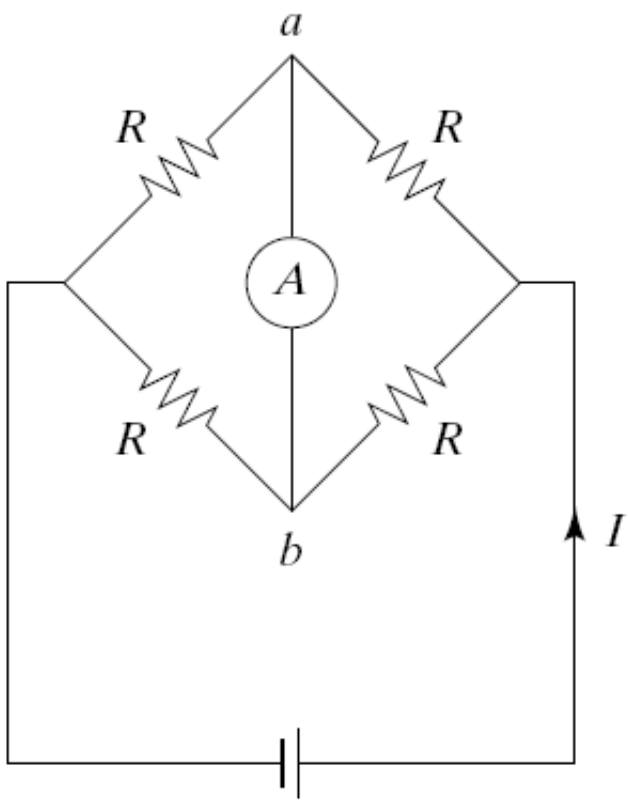
1. all the charge continues to flow through the bulb.
2. half the charge flows through the wire, the other half continues through the bulb.
3. all the charge flows through the wire.
4. none of the above

The light bulbs in the circuit are identical. When the switch is closed,



1. both go out.
2. the intensity of light bulb *A* increases.
3. the intensity of light bulb *A* decreases.
4. the intensity of light bulb *B* increases.
5. the intensity of light bulb *B* decreases.
6. some combination of 1–5 occurs.
7. nothing changes.

An ammeter A is connected between points a and b in the circuit below, in which the four resistors are identical. The current through the ammeter is



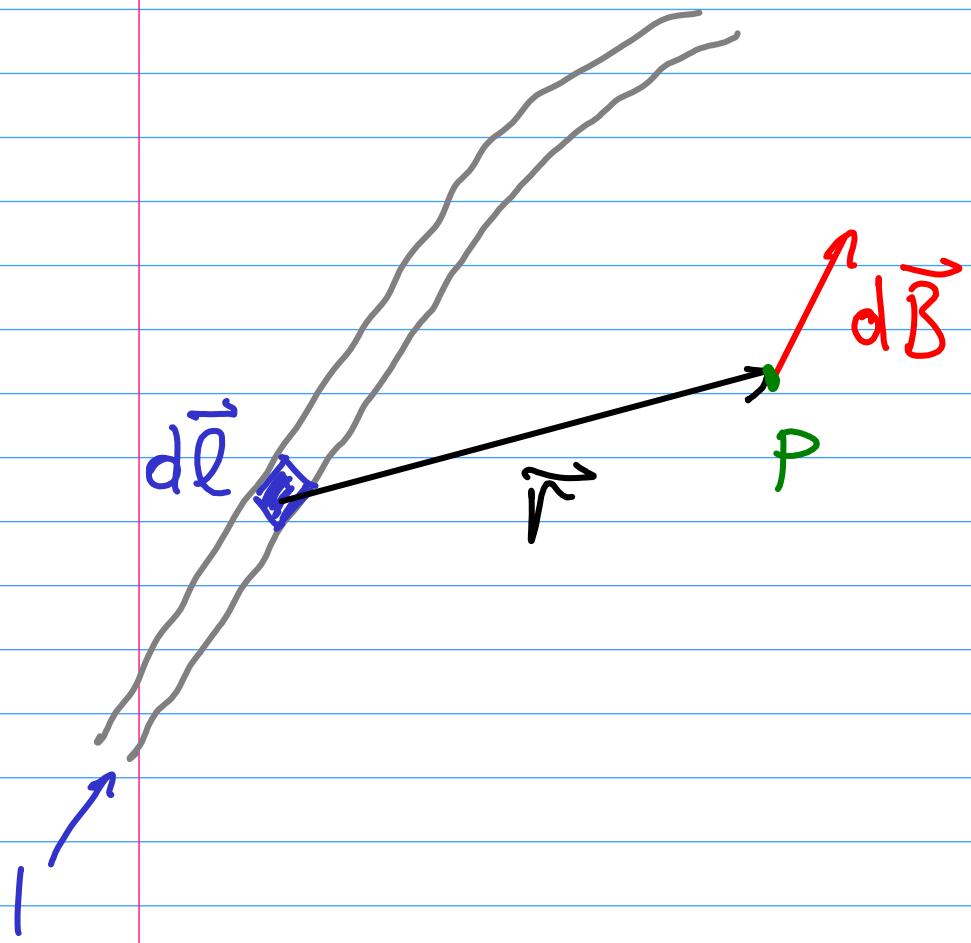
1. $I/2$.
2. $I/4$.
3. zero.
4. need more information

Ampèregesetz:
praktisch für
symm. Geometrien

vgl. Gauß bei $\vec{E}$
allgm. Ladungsverteilung:
Coulombgesetz

Nun das "Gleiche magnetisch"

Biot-Savart-Gesetz



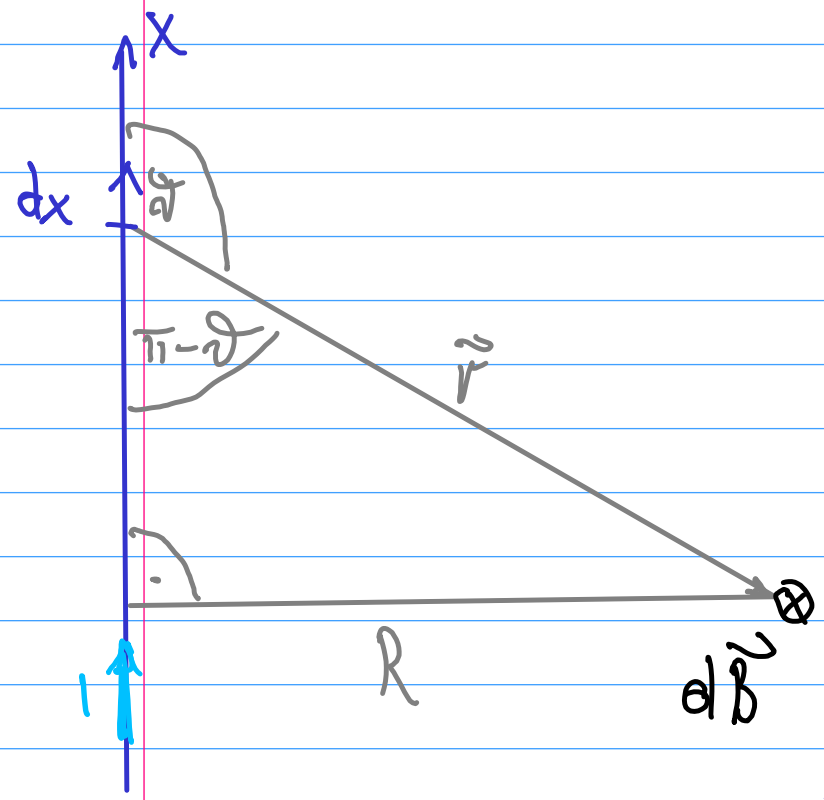
$$\vec{B} = \frac{\mu_0}{2\pi} \frac{\vec{I} \times \vec{r}}{r^2}$$

$$\boxed{d\vec{B} = \frac{\mu_0 I}{4\pi r^3} d\vec{l} \times \vec{r}}$$

$$= \frac{\mu_0 I}{4\pi r^2} d\vec{l} \times \vec{e}_r$$

$$\left(\oint \vec{B} d\vec{A} = 0 \wedge \oint \vec{B} d\vec{s} = \mu_0 I \Rightarrow \ldots \right)$$

"Beweisersatz": Feld eines Drahts



$$B = \int dB = \frac{\mu_0 I}{4\pi} \int \frac{d\vec{l} \times \vec{e_r}}{r^2}$$

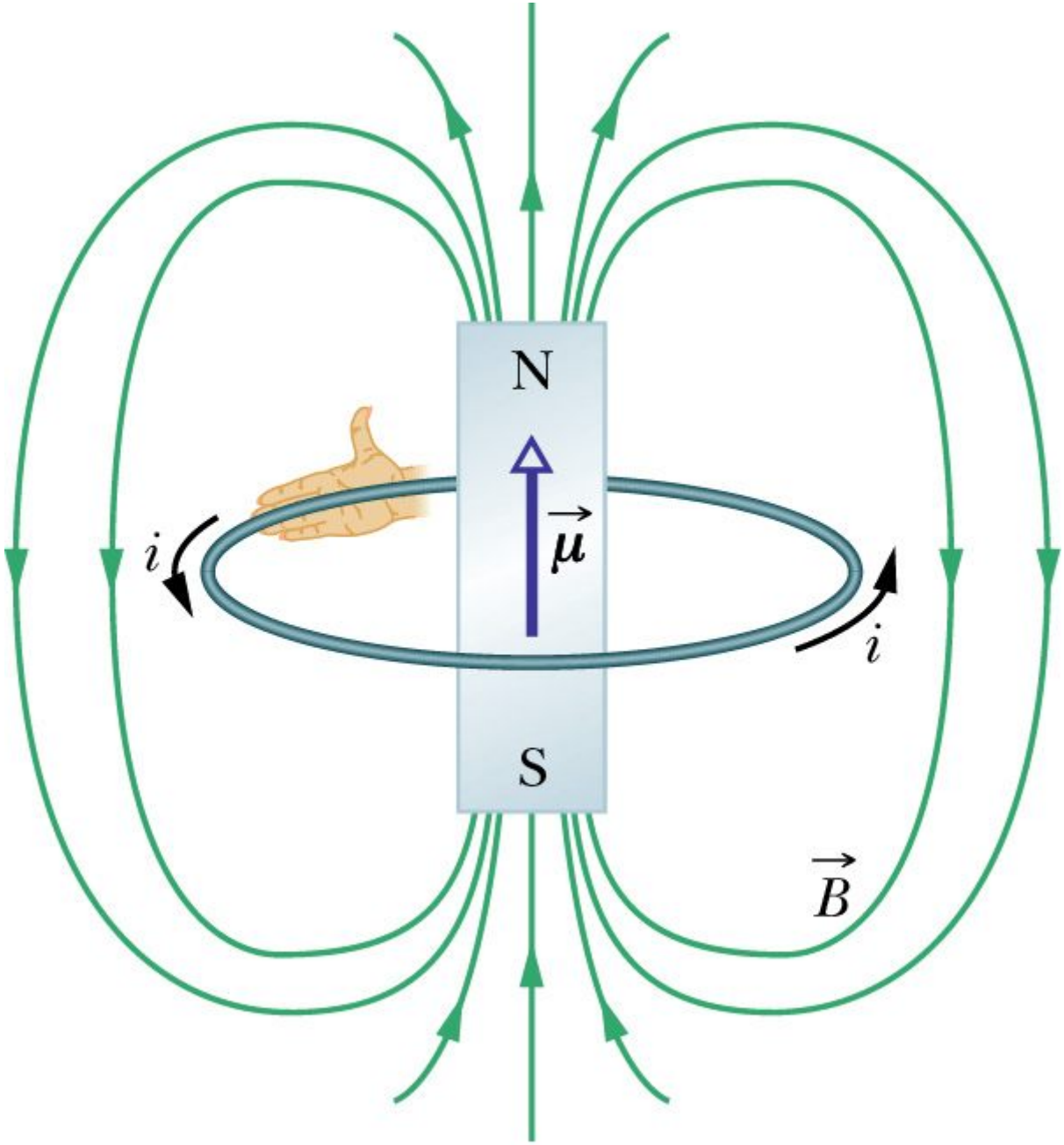
$$= \frac{\mu_0 I}{4\pi} \int_{x=-\infty}^{\infty} \frac{\sin\vartheta}{r^2}\, dx$$

$$r = \sqrt{x^2+R^2} \qquad \sin\vartheta = \sin(\pi-\vartheta) = \frac{R}{\sqrt{x^2+R^2}}$$

$$B = \frac{\mu_0 I}{4\pi} R \int \frac{dx}{(x^2+R^2)^{3/2}}$$

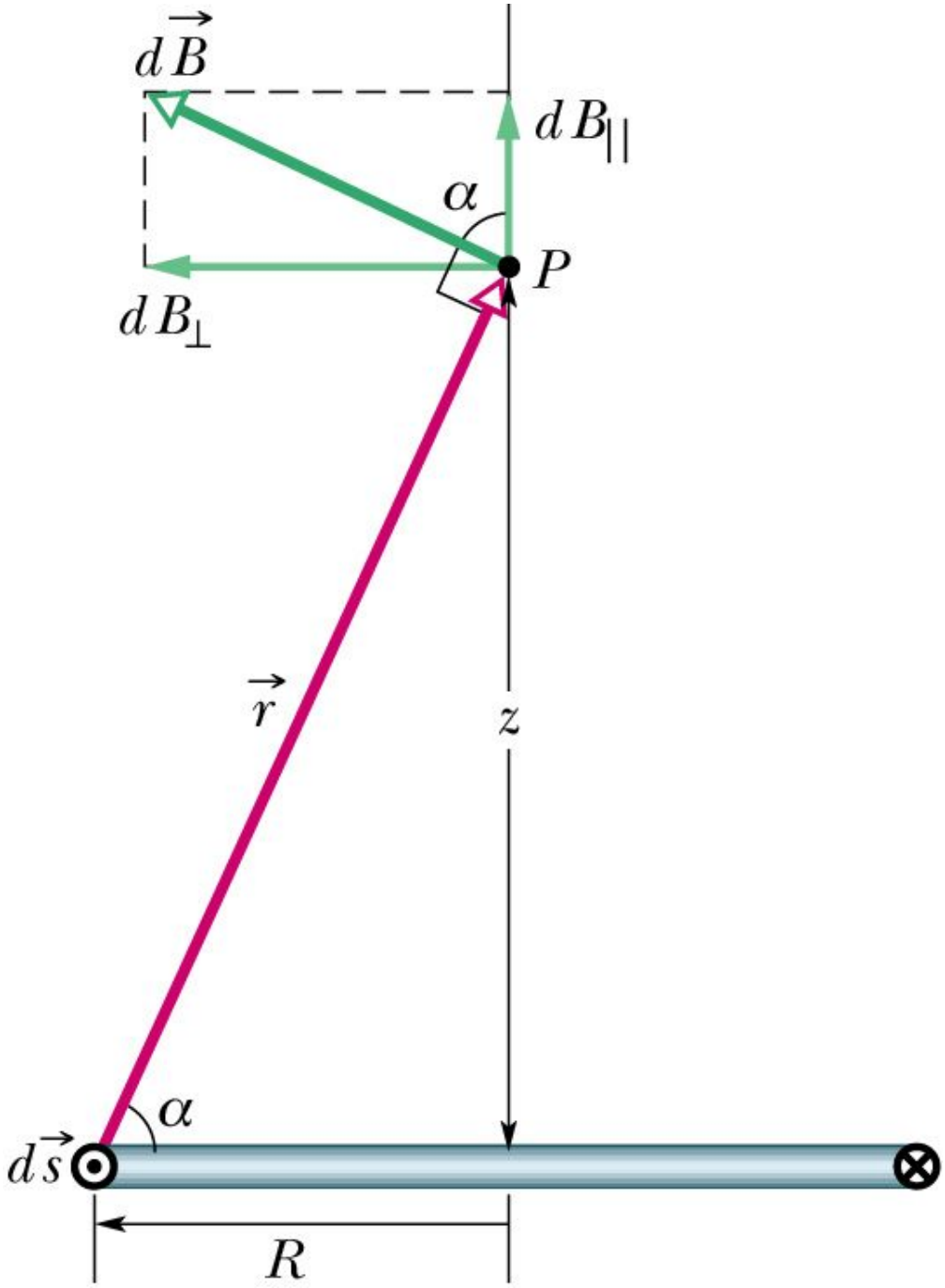
$$= \frac{\mu_0 I}{4\pi} \frac{1}{R} \frac{x}{(x^2+R^2)^{1/2}} \Bigg|_{-\infty}^{\infty} = \frac{\mu_0 I}{2\pi R} \checkmark$$

Magnetisches Dipolfeld

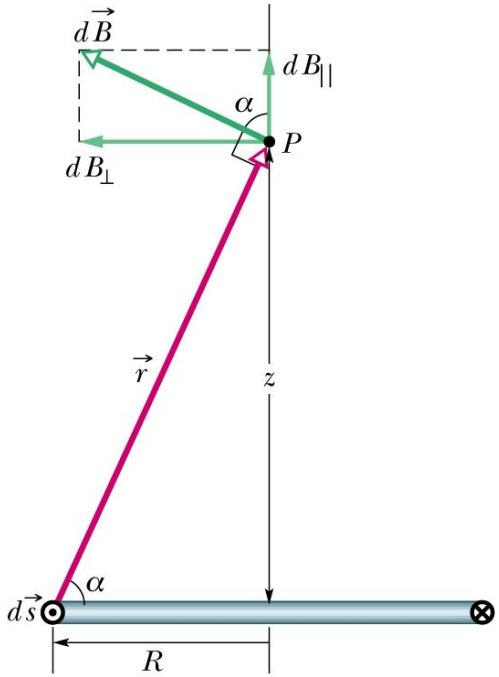


Halliday, 30-21

Magnetisches Dipolfeld - Berechnung



Halliday, 30-22



$$dB = \frac{\mu_0}{4\pi} I \frac{d\vec{s} \times \vec{e_r}}{r^2}$$

sin 90°, denn $\vec{r} \perp$ Drahtstück

$$dB_{\parallel} = dB \cdot \cos\alpha$$

$$dB_{\parallel} = \frac{\mu_0 I}{4\pi} \frac{\cos\alpha \, ds}{r^2}$$

$$dB_{\parallel} = \frac{\mu_0 I}{4\pi} \frac{R \, ds}{(R^2+z^2)^{3/2}}$$

$$B_{\parallel} = \text{—}\,''\,\text{—} \int ds \quad ; \int ds = 2\pi R$$

$$\Rightarrow B(z) = \frac{\mu_0 I R^2}{2(R^2+z^2)^{3/2}}$$

$$r = \sqrt{R^2+z^2}$$

$$\cos\alpha = \frac{R}{r} = \frac{R}{\sqrt{R^2+z^2}}$$

Punkt weit weg von Ring $(R \ll z)$

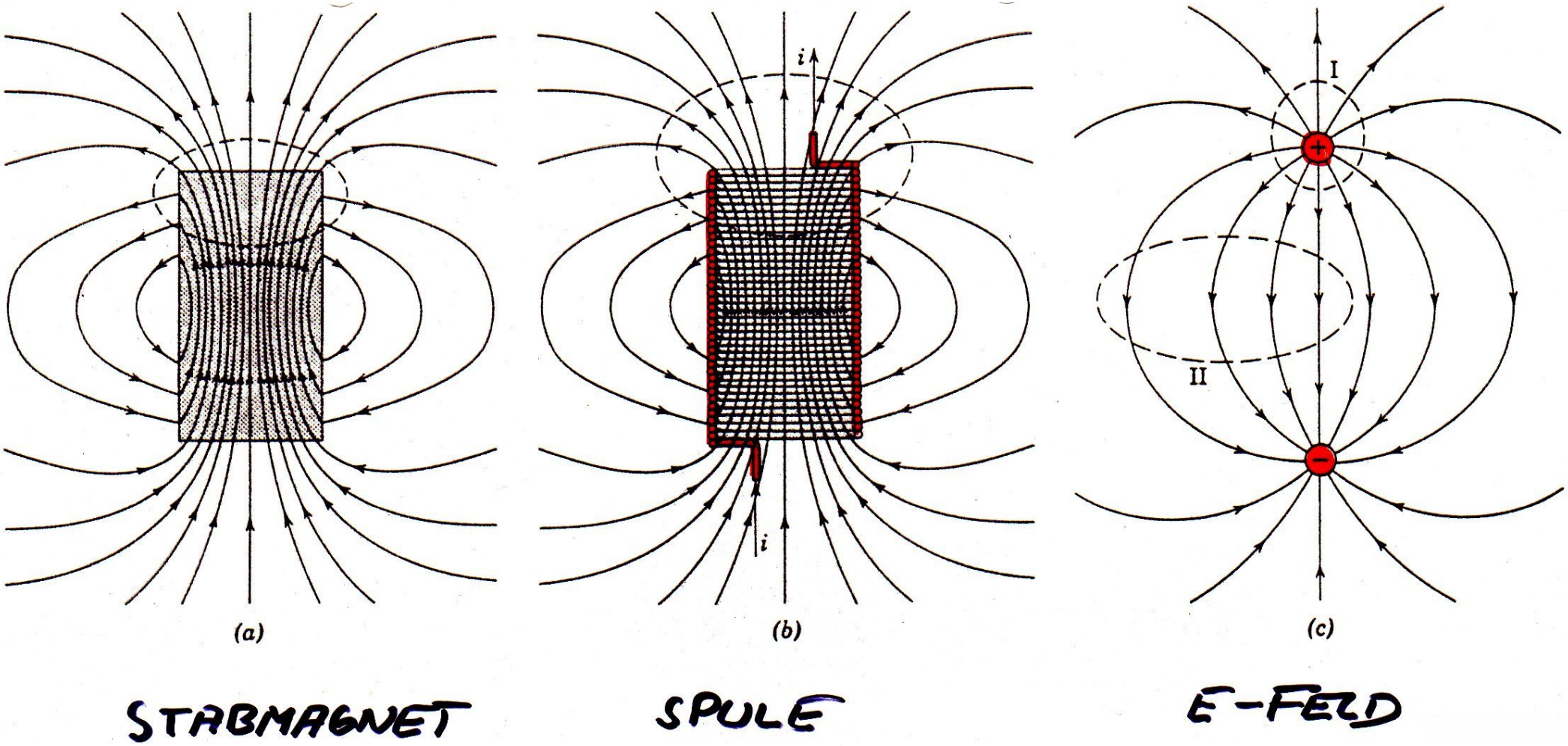
$$B(z) \approx \frac{\mu_0 I R^2}{2 z^3}$$

$$A = \pi R^2 \Longrightarrow B(z) = \frac{\mu_0}{2\pi} \frac{I \cdot A}{z^3}$$

Dipolmoment

$$\vec{B} = \frac{\mu_0}{2\pi} \frac{\vec{\mu}}{z^3} \; ; \; \vec{\mu} = I \cdot \vec{A}$$

Dipolfelder

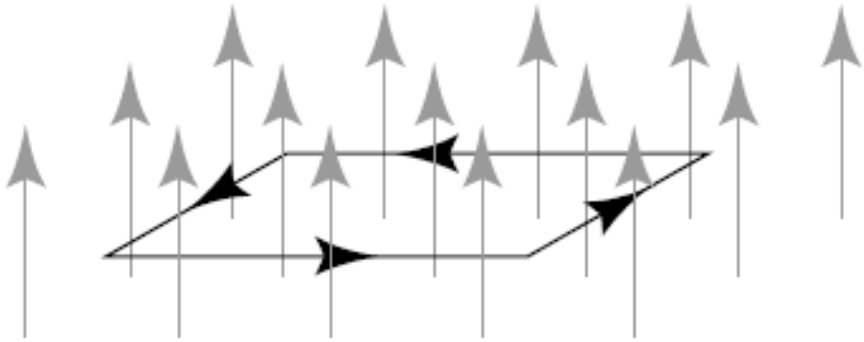


Quellenfrei vs. Punktladungen

A sphere of radius R is placed near a long, straight wire that carries a steady current I. The magnetic field generated by the current is B. The total magnetic flux passing through the sphere is

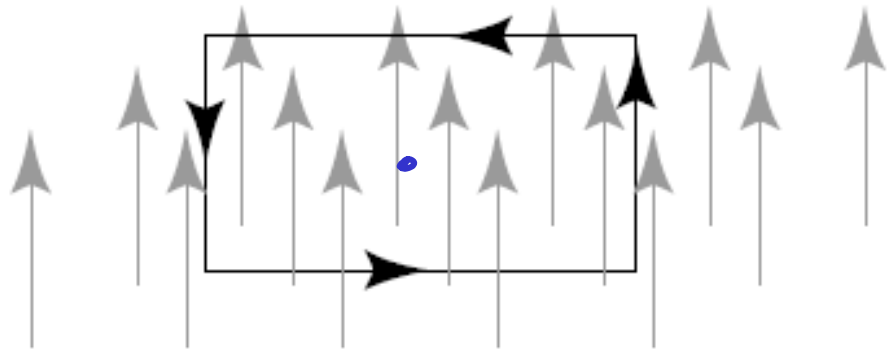
1. $\mu_o I$.
2. $\mu_o I/(4\pi R^2)$.
3. $4\pi R^2 \mu_o I$.
4. zero.
5. need more information

A rectangular loop is placed in a uniform magnetic field with the plane of the loop perpendicular to the direction of the field. If a current is made to flow through the loop in the sense shown by the arrows, the field exerts on the loop:



1. a net force.
2. a net torque.
3. a net force and a net torque.
4. neither a net force nor a net torque.

A rectangular loop is placed in a uniform magnetic field with the plane of the loop parallel to the direction of the field. If a current is made to flow through the loop in the sense shown by the arrows, the field exerts on the loop:

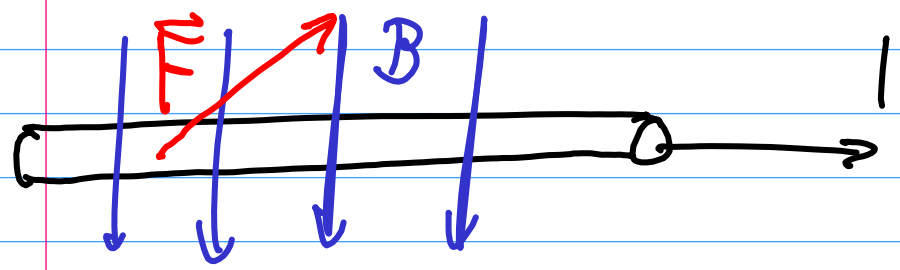


1. a net force.
2. a net torque.
3. a net force and a net torque.
4. neither a net force nor a net torque.

Der Halleffekt

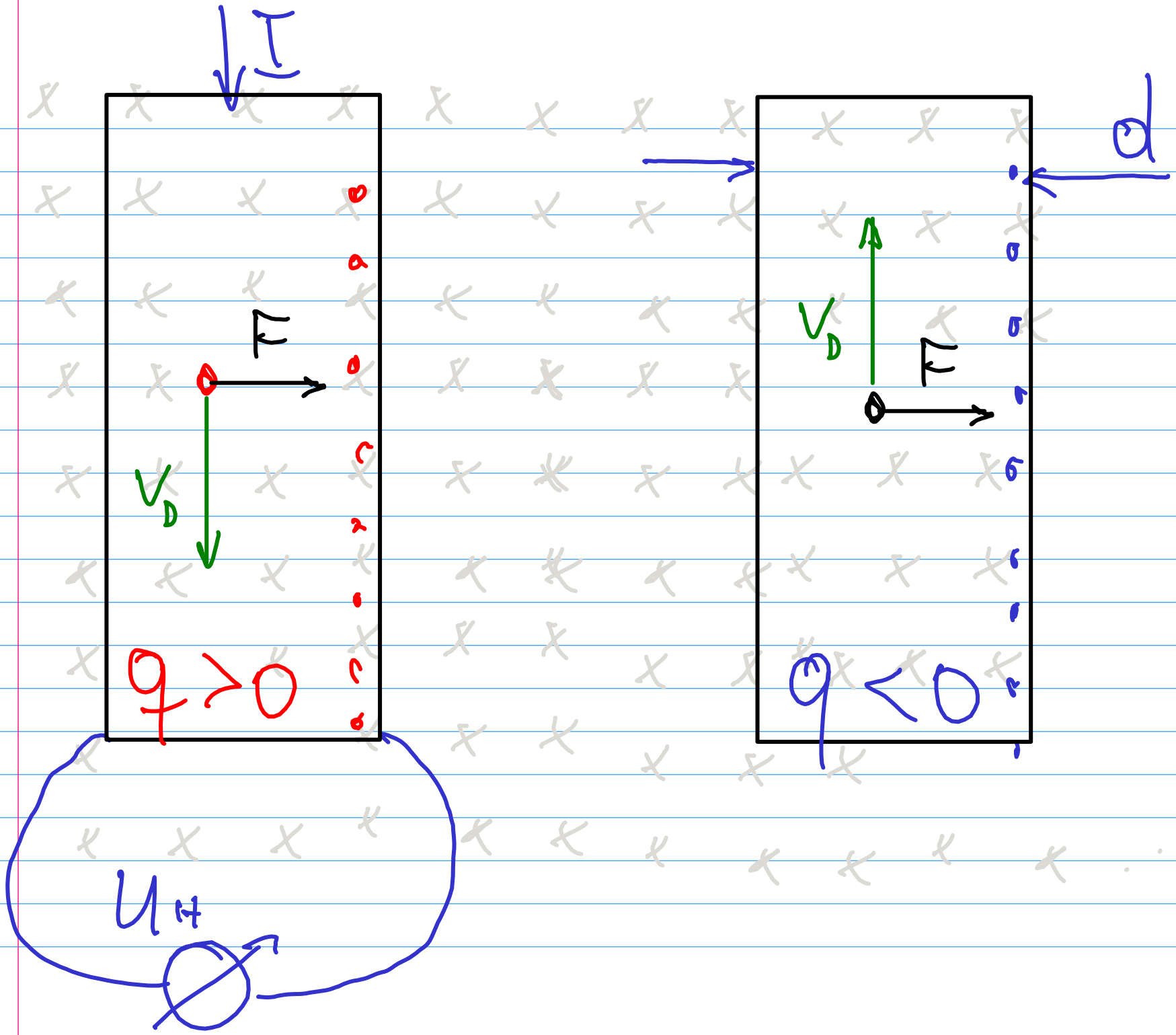
Lorentzkraft auf Ladungsträger in gleiche Richtung für $q<0$ und $q>0$!

$\Rightarrow v<0$ $\quad$ $v>0$



$$\vec{F} = q\vec{v}\times\vec{B}$$

Halls Idee: Im B-Feld sollten sich die bewegten Ladungen auf einer Probenseite ansammeln


I
F
V_D
$q > 0$
U_H
d
V_D
F
$q < 0$

Ergebnisse zum Hallwiderstand

$$F_M = q\,\vec{v}_D \times \vec{B} \qquad E_{Hall} = \frac{U_H}{d}$$

$$\Rightarrow F_E = \frac{U_H}{d}\,q$$

$$F_M + F_E = 0$$

$$\Rightarrow \vec{E}_{Hall} = -\vec{v}_D \times \vec{B}$$

$$j = n e v_D \quad \Rightarrow E_{Hall} = -\frac{j}{ne} B$$

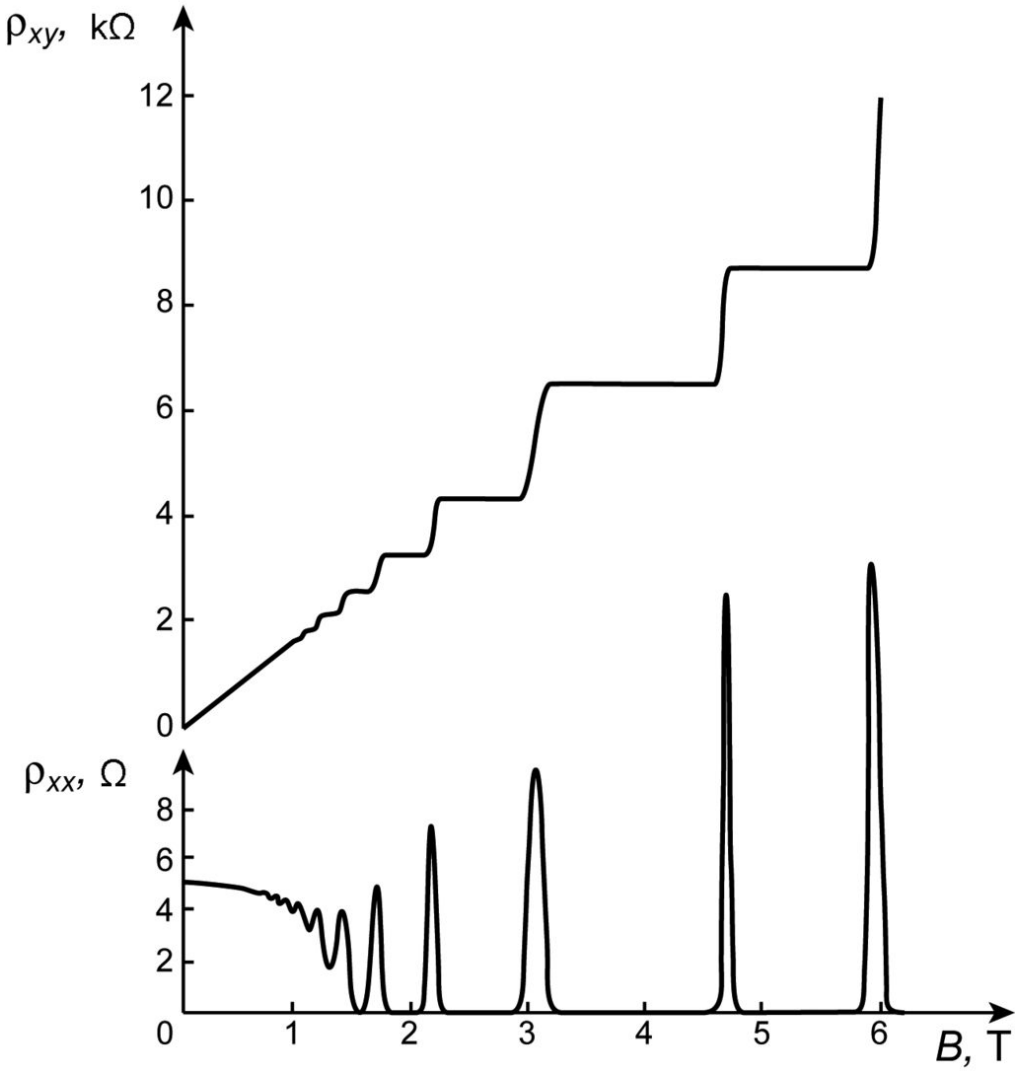
$$E_{Hall} = R_{Hall}\, j\, B \Rightarrow R_{Hall} = -\frac{1}{ne}$$

Halleffekt

Metall	Valenz	$-1/R_H ne$
Li	1	0,8
Na	1	1,2
K	1	1,1
Rb	1	1,0
Cs	1	0,9
Cu	1	1,5
Ag	1	1,3
Au	1	1,5
Be	2	-0,2
Mg	2	-0,4
Al	3	-0,3

Quantenhalleffekt

$R_H = h/ne^2 \quad n = 1, 2, \ldots$



Quanten-Hall-Widerstands-Normal zur Bewahrung und Weitergabe der Widerstandseinheit.

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Zukunft des A? SET

Josephsoneffekt

Tunneln von Cooperpaaren zwischen zwei Supraleitern über Isolator oder Normalleiter

Mikrowelle mit f einstrahlen: Sprünge in I(U)-Kennlinie bei

$$U_n = n\,\Phi_0\,f \qquad n = 1, 2, \ldots \qquad \Phi_0 = h/2e$$

Phys. Rev. **177**, 639 (1969)

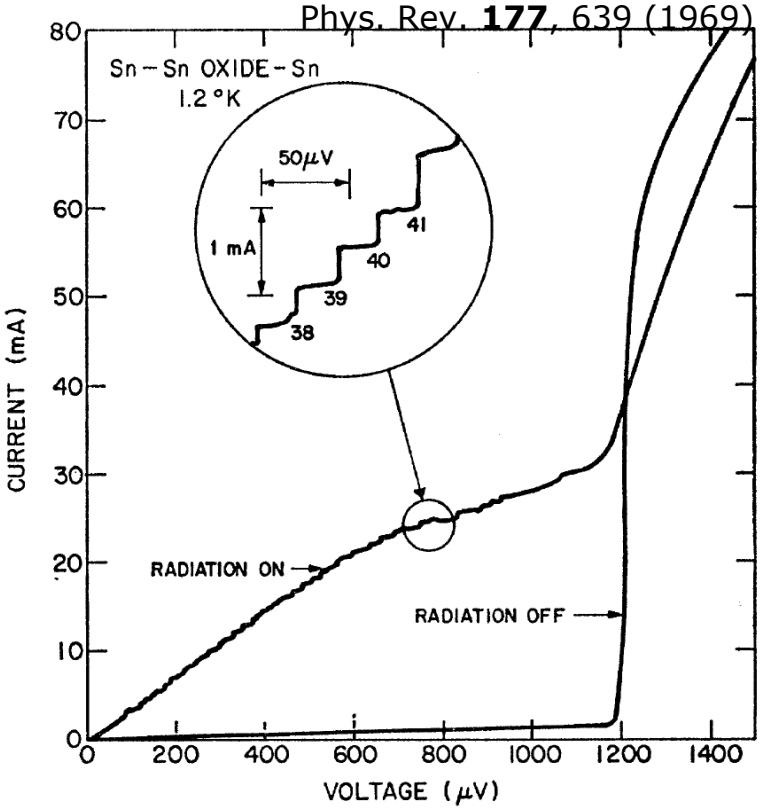
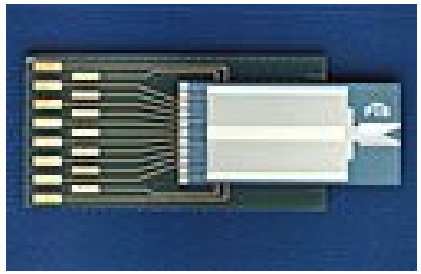


FIG. 3. *I-V* curves of a Sn-Sn oxide-Sn tunnel junction displaying radiation-induced current steps.



Josephson-Spannungs-Normal

~ 14000 Josephson-Elemente in Reihe ergeben Spannung von maximal 14 V

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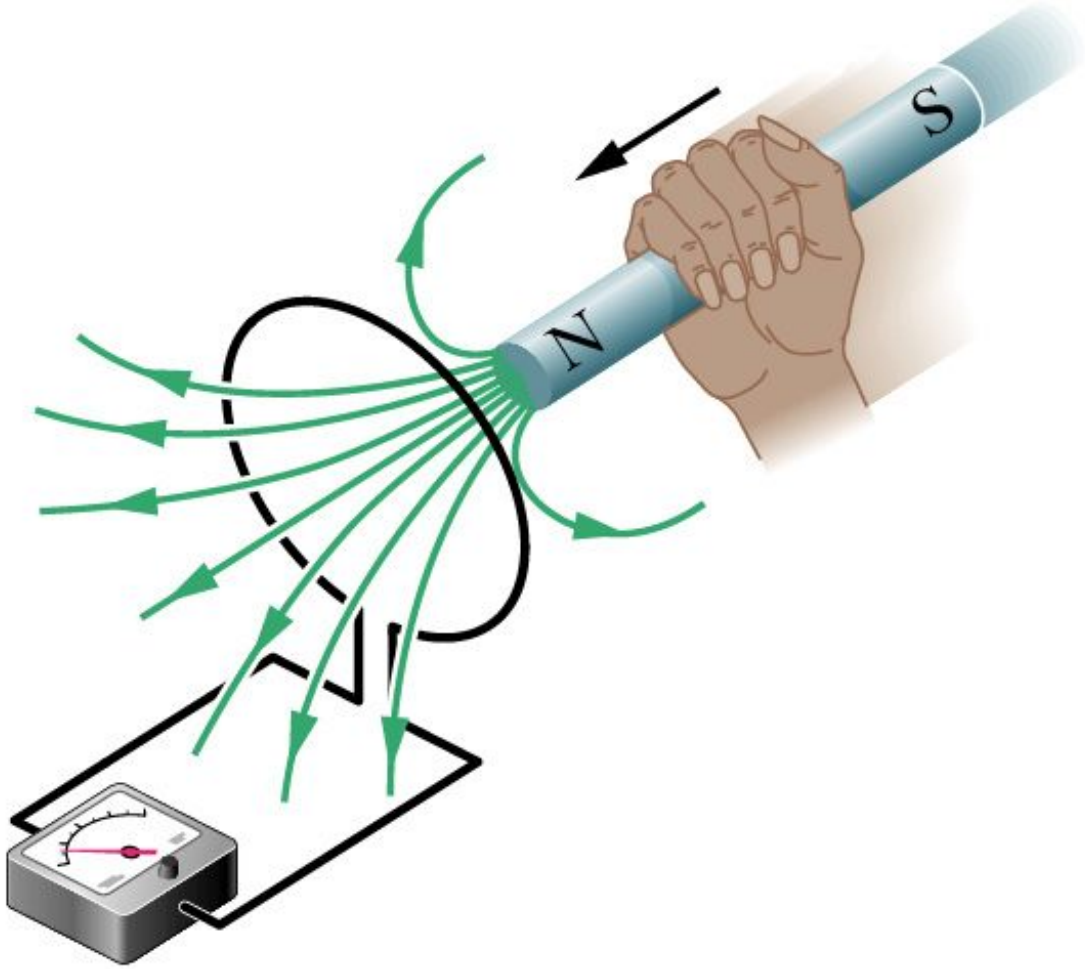
Zukunft des A? SET

Induktion:

Faradaysches Gesetz

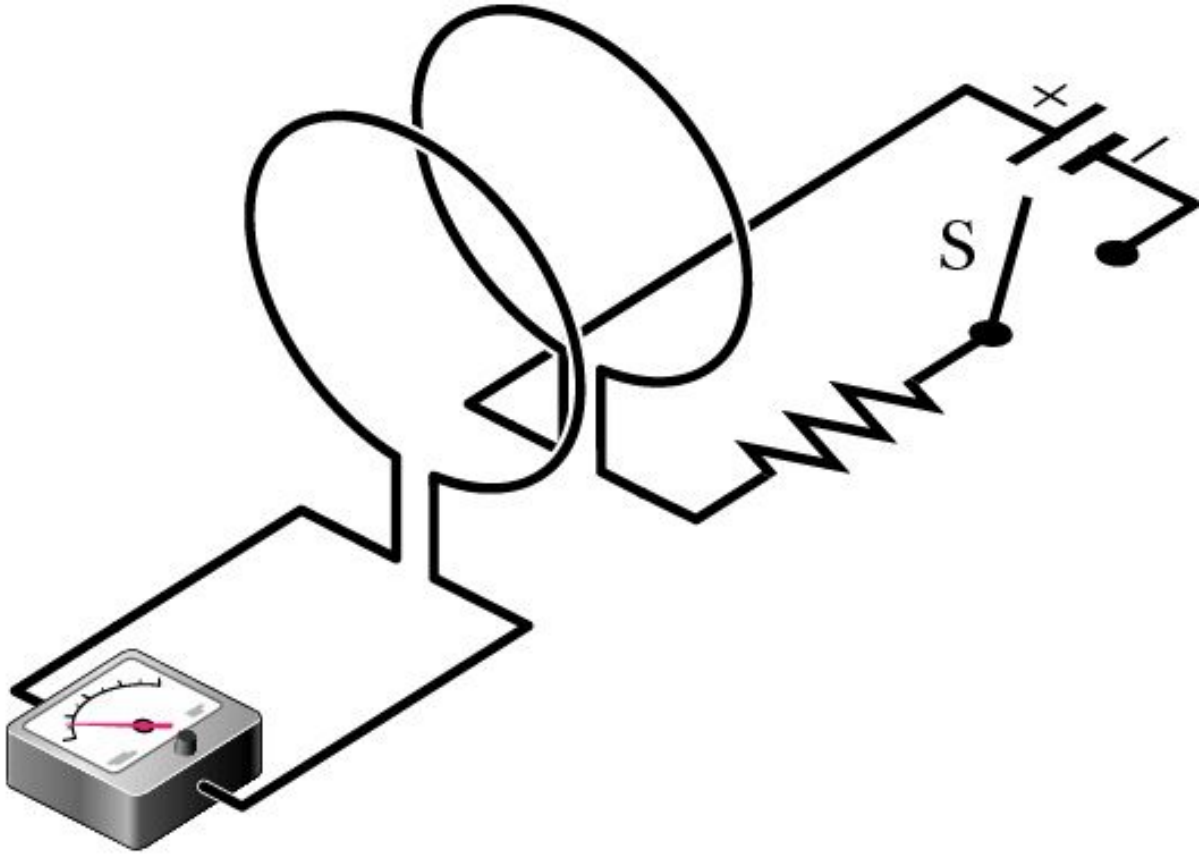
Vijo

Induktion bei bewegtem Magnet



Halliday, 31-1

Induktion bei veränderlichem Strom



Halliday, 31-2

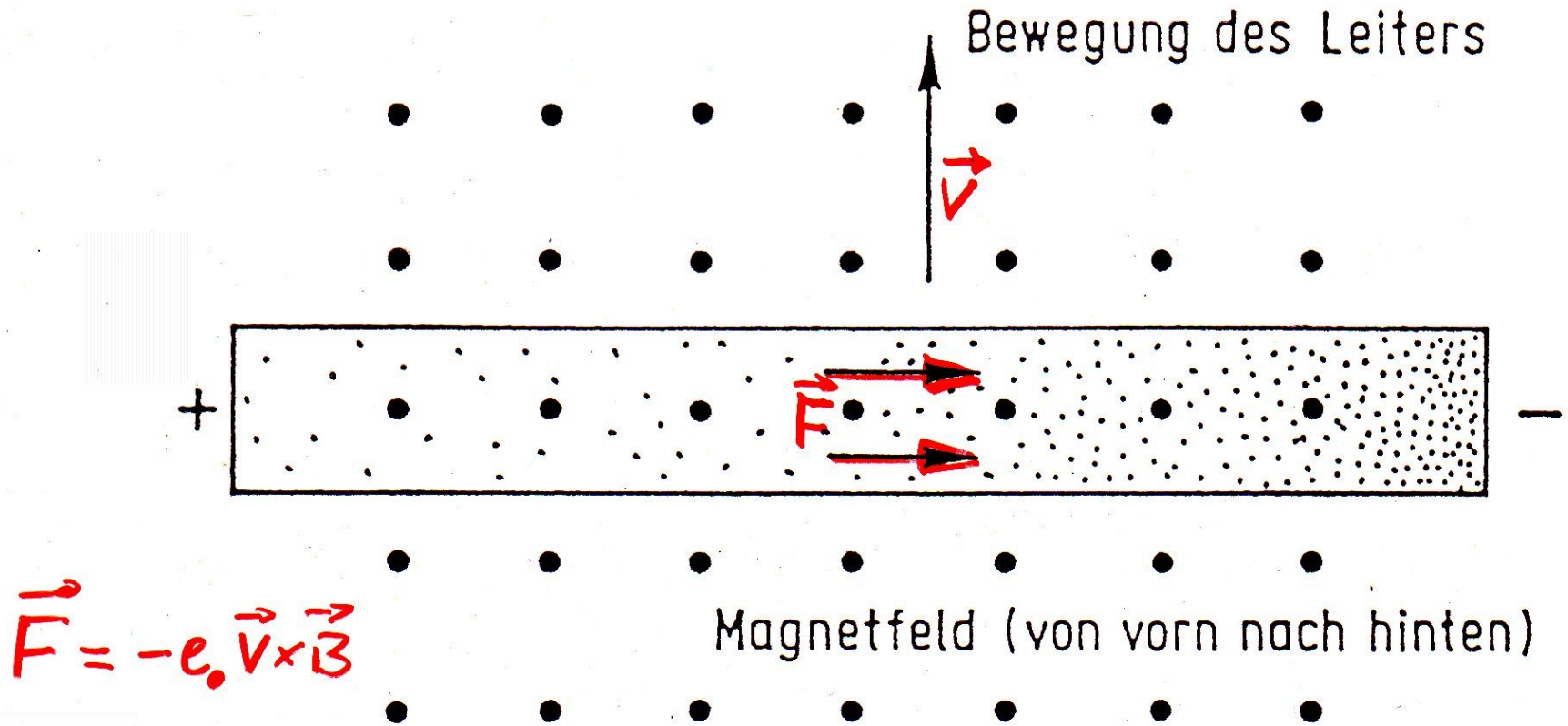
Ursprüngliche Exp.: Faraday, Henry, ≈1830

Quantitative Form:

$$U_{ind} = -\dot{\Phi}_m = -\frac{d}{dt}\int \vec{B}\, d\vec{A}$$

Spule mit N Windungen: $U_{ind} = -N\dot{\Phi}_m$

Φ_m ändern? B, A, $\sphericalangle\, \vec{A}, \vec{B}$

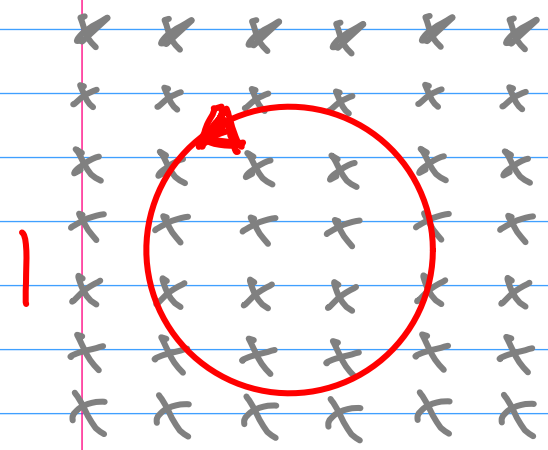


$\vec{F} = -e_0 \vec{v} \times \vec{B}$

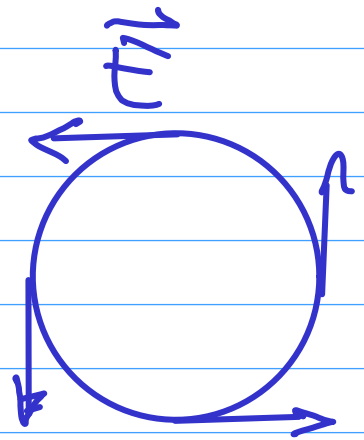
Abb. 277 Zur Entstehung der Induktionsspannung in einem
anhäufung rechts)

Messung: Schleife! $\rightsquigarrow \dot{\Phi} \neq 0$

U_{ind} ist Folge von $\vec{E}_{ind}$



$\hat{=}$



induziertes $\vec{E}$-Feld

Das gilt auch <u>ohne</u> Leiterschleife.

Arbeit an q_0, wenn q_0 um Kreis geführt wird

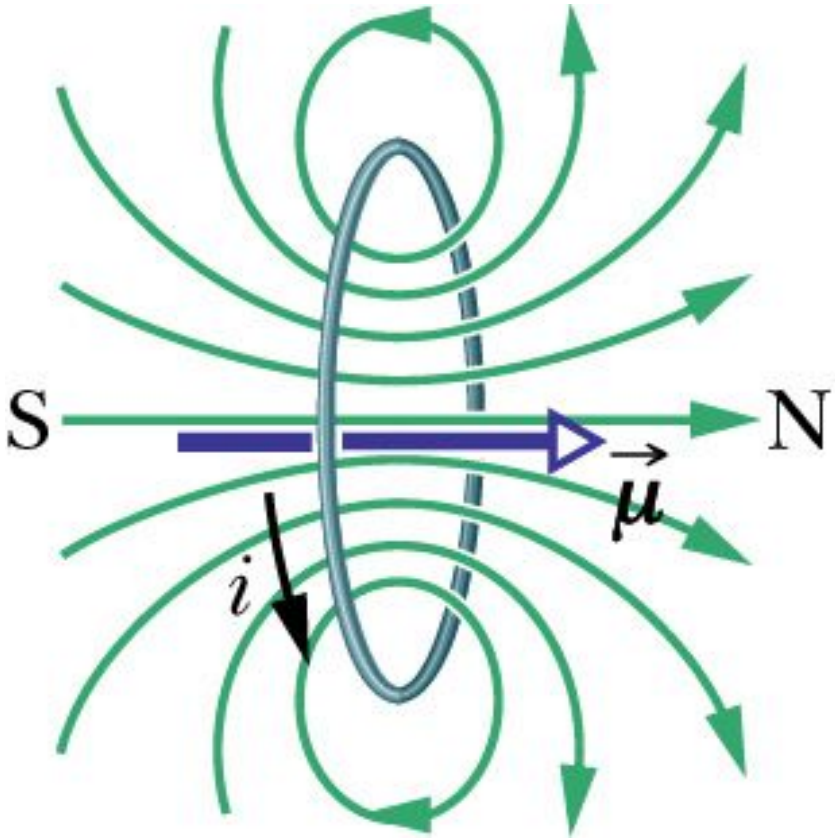
$$W = \oint \vec{F}\, d\vec{s} = q_0 \int \vec{E}_{ind}\, d\vec{s}$$

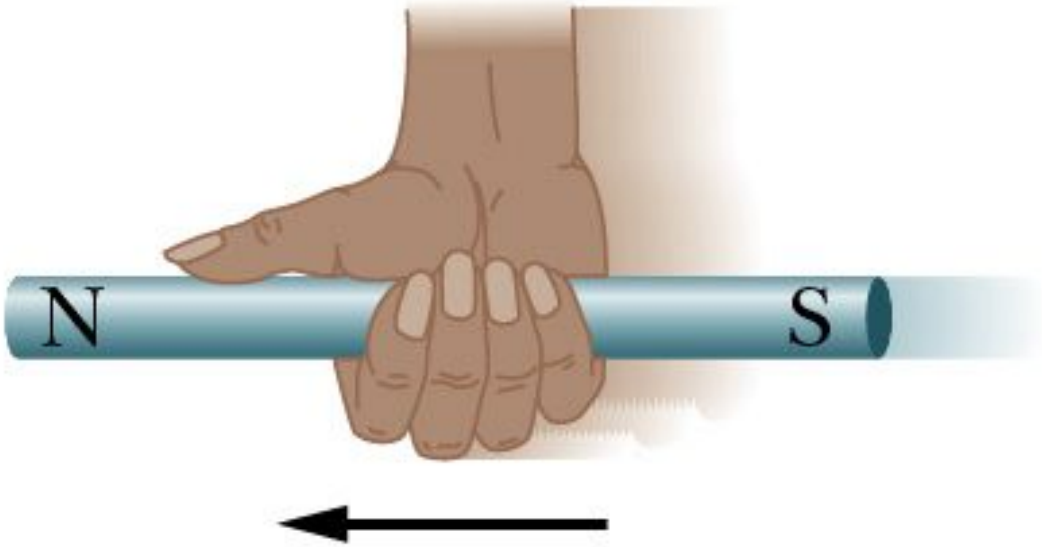
$$W = q_0 U_{ind} \rightarrow U_{ind} = \boxed{\oint \vec{E}_{ind}\, d\vec{s} = -\dot{\Phi}_m}$$

e-stat.K: $\oint \vec{E}\, d\vec{s} = 0$

$\Updownarrow$ $\exists$ Potential

Lenzsche Regel



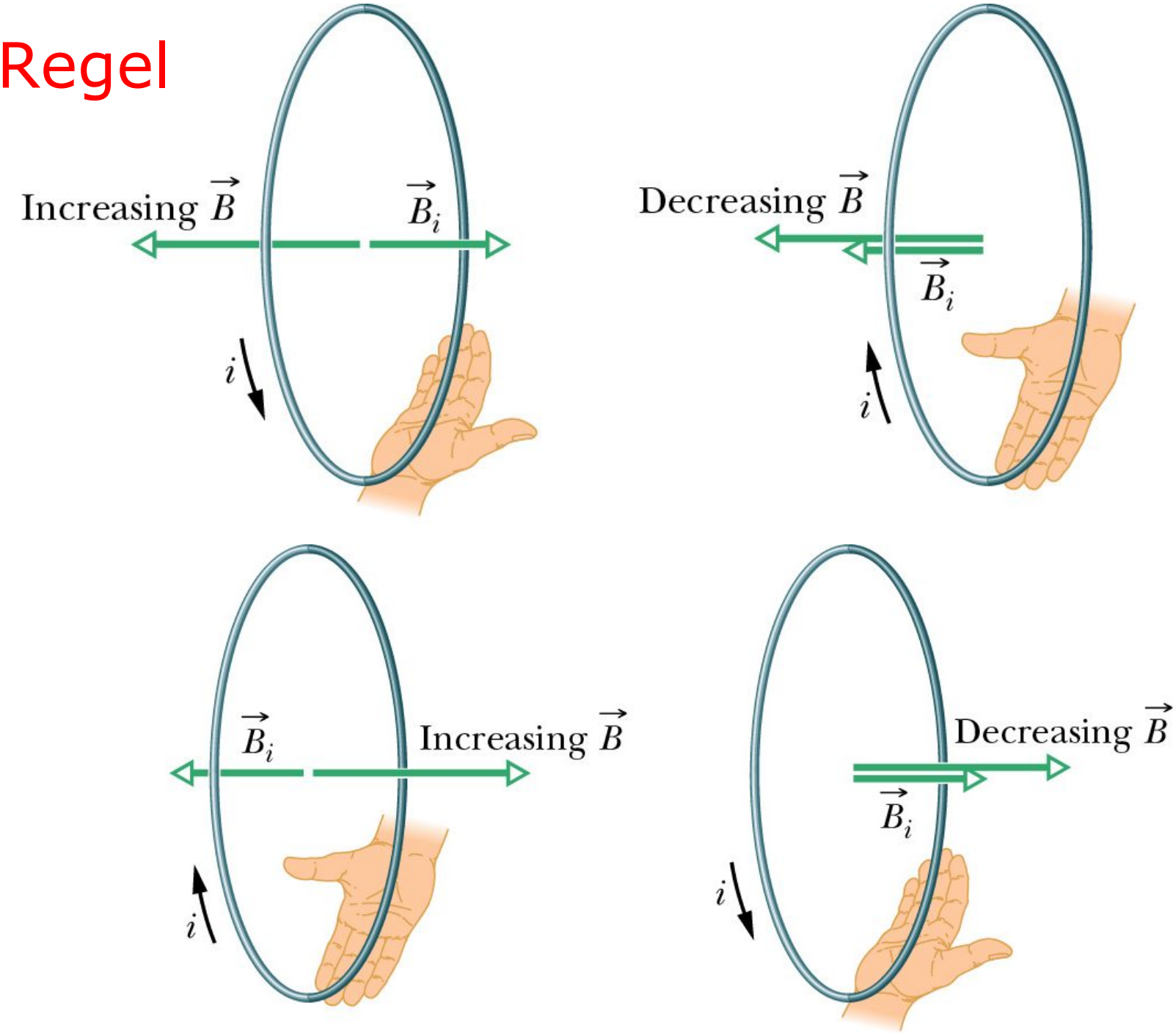


Halliday, 31-4

Lenzsche Regel

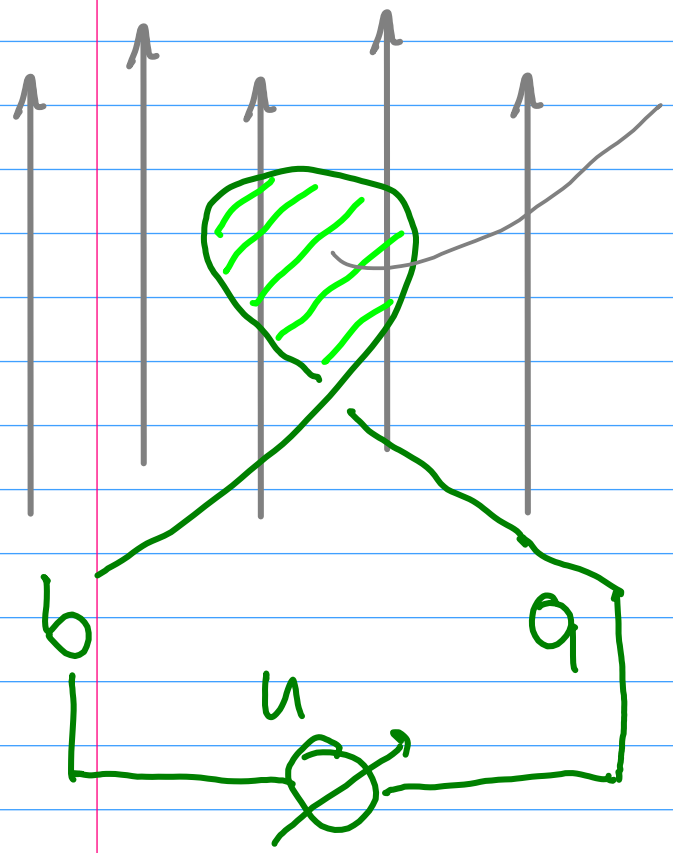
Induzierter Strom so, dass das damit verbundene B-Feld der Änderung von Φ_M entgegen wirkt.

Lenzsche Regel



(c) (d)

Zum Vorzeichen beim Induktionsgesetz



Fläche $\vec{A}$, Vorzeichen wählbar

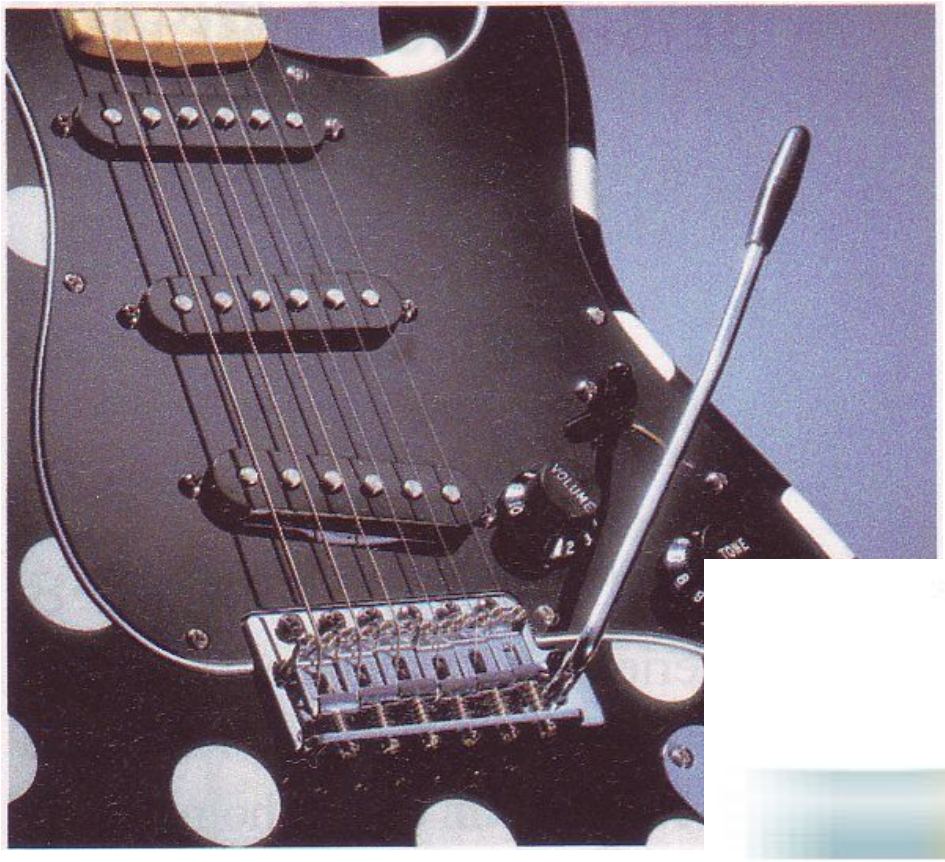
$\Rightarrow$ Vorzeichen von Φ, $\dot{\Phi}$ wählbar

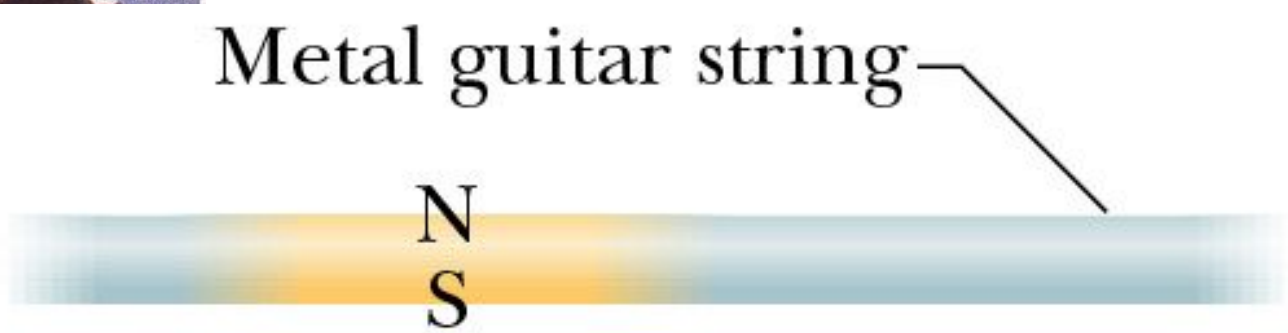
Wann gilt $U_{ind} = -\dot{\Phi}$?

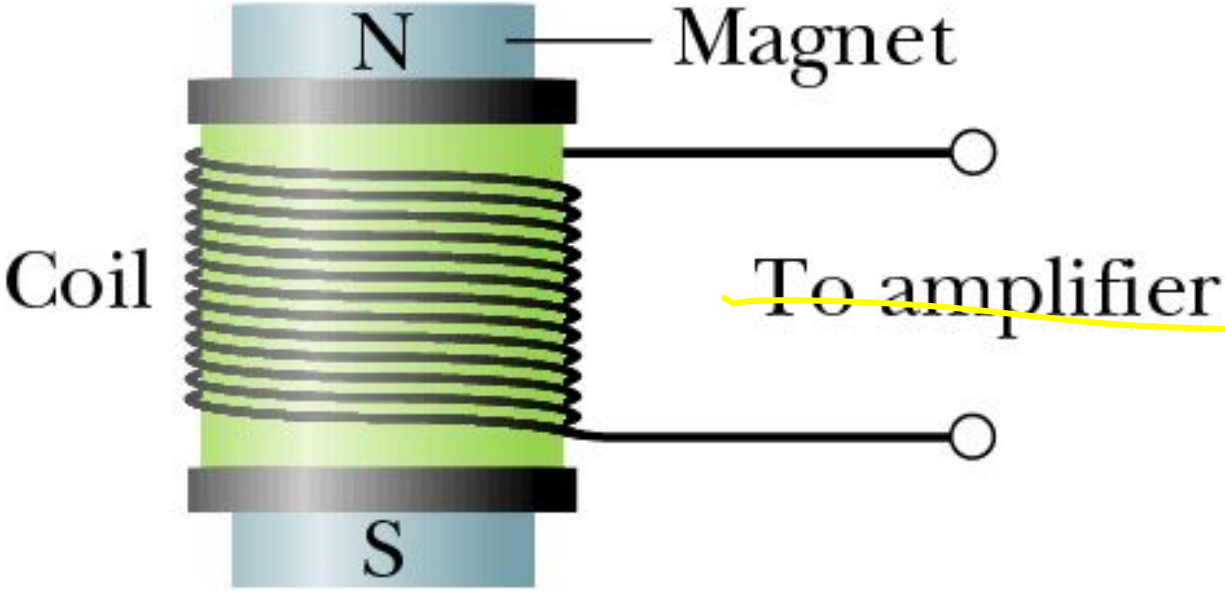
Rechte-Hand-Regel

Wenn der Schraubensinn der Messschleife positiv bzgl. Fluss, dann gilt $u = -\dot{\Phi}$

(Bergmann-Schäfer)

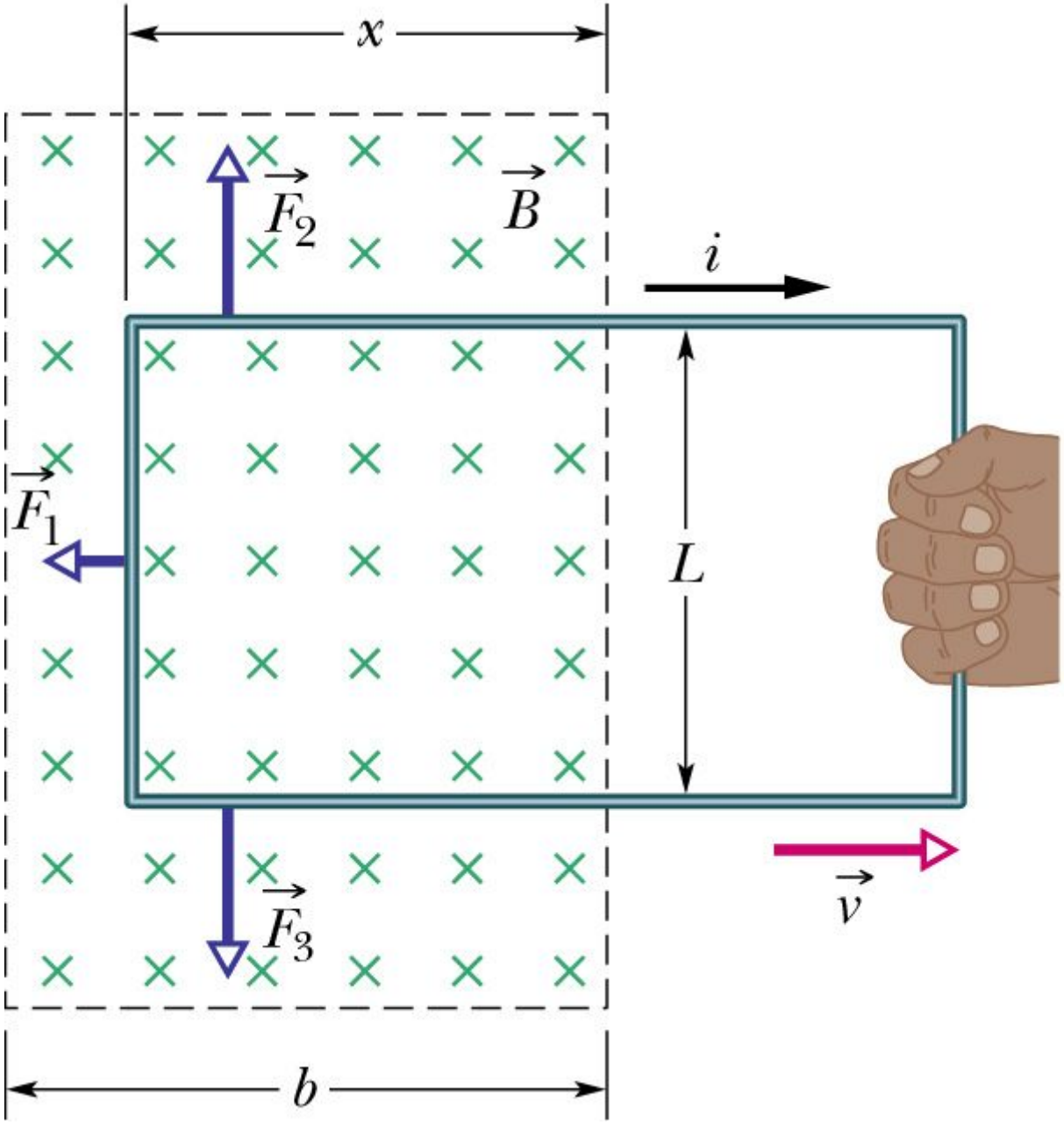






Halliday, 31-6

Induktion und Energieerhaltung



Halliday, 31-10

Zug ändert Fläche ⇝ Φ_M variiert ⇝ i ⇝ $\vec{F}_1, \vec{F}_2 \ldots$

$$\Phi = BA = BLx$$

$$|U| = \dot{\Phi} = BLv$$

$$i = \frac{U}{R} = BL\frac{v}{R} \quad (1)$$

$$\vec{F} = i\,\vec{L} \times \vec{B}$$; nur F_1 relevant

$$F_1 = iLB \overset{(1)}{=} \frac{B^2L^2v}{R}$$

$$P_{mech} = F_1 v = \frac{B^2L^2v^2}{R}$$

$$P_{mech} = F_L v = \frac{B^2 l^2 v^2}{R}$$

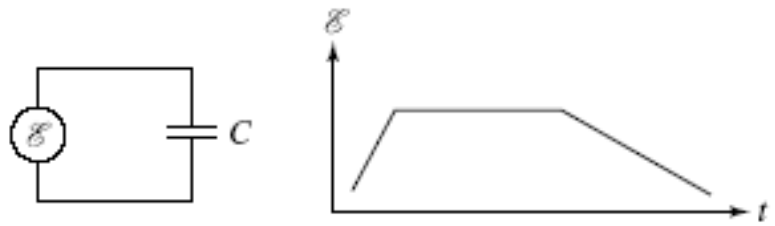
$$P_{elek} = I^2 R = \frac{B^2 l^2 v^2}{R^2} R = P_{mech}$$

$\Rightarrow$ Wirbelstrombremse

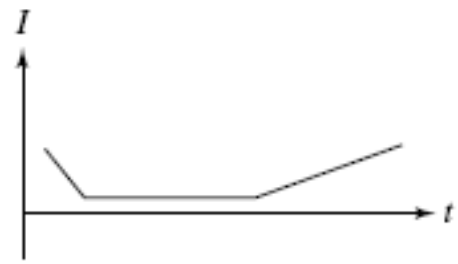
Au – Fe

Messing – magn. Fe

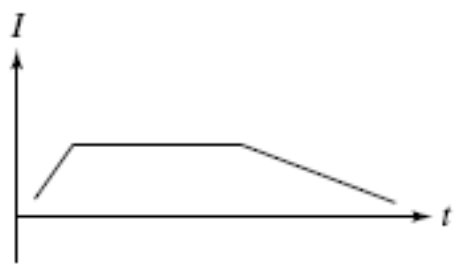
A capacitor is connected to a varying source of emf. Given the behavior of $\mathscr{E}$ shown, the current through the wires changes according to:



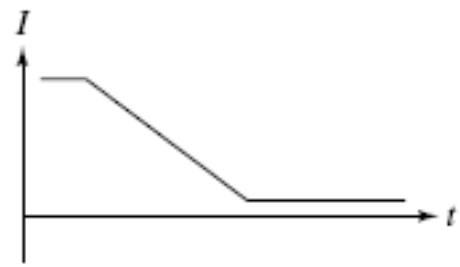
1



2



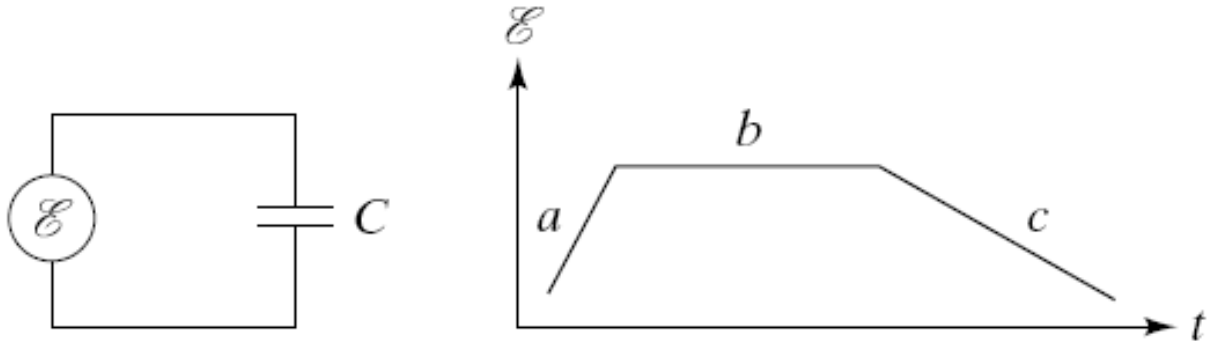
3



4

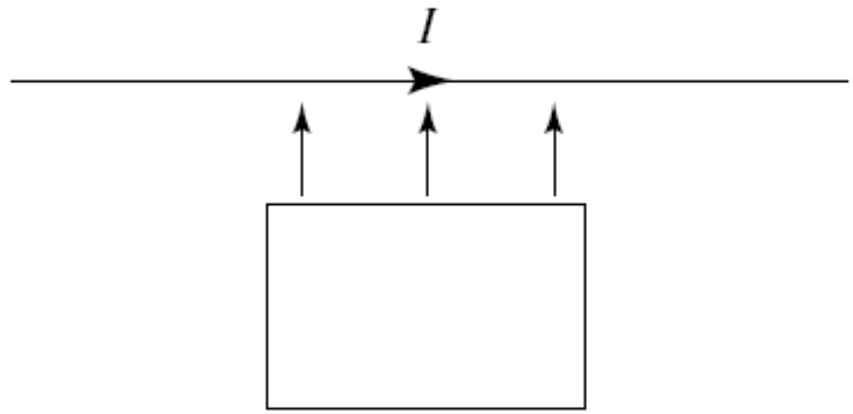
5. none of the above

A capacitor is connected to a varying source of emf. The work done by the source during the time intervals a, b, and c is



1. positive, negative, and zero, respectively.
2. negative, positive, and zero, respectively.
3. always positive.
4. positive, zero, and negative, respectively.
5. always negative.
6. zero, positive, and zero, respectively.
7. zero, negative, and zero, respectively.

A long, straight wire carries a steady current I. A rectangular conducting loop lies in the same plane as the wire, with two sides parallel to the wire and two sides perpendicular. Suppose the loop is pushed toward the wire as shown. Given the direction of I, the induced current in the loop is



1. clockwise.
2. counterclockwise.
3. need more information