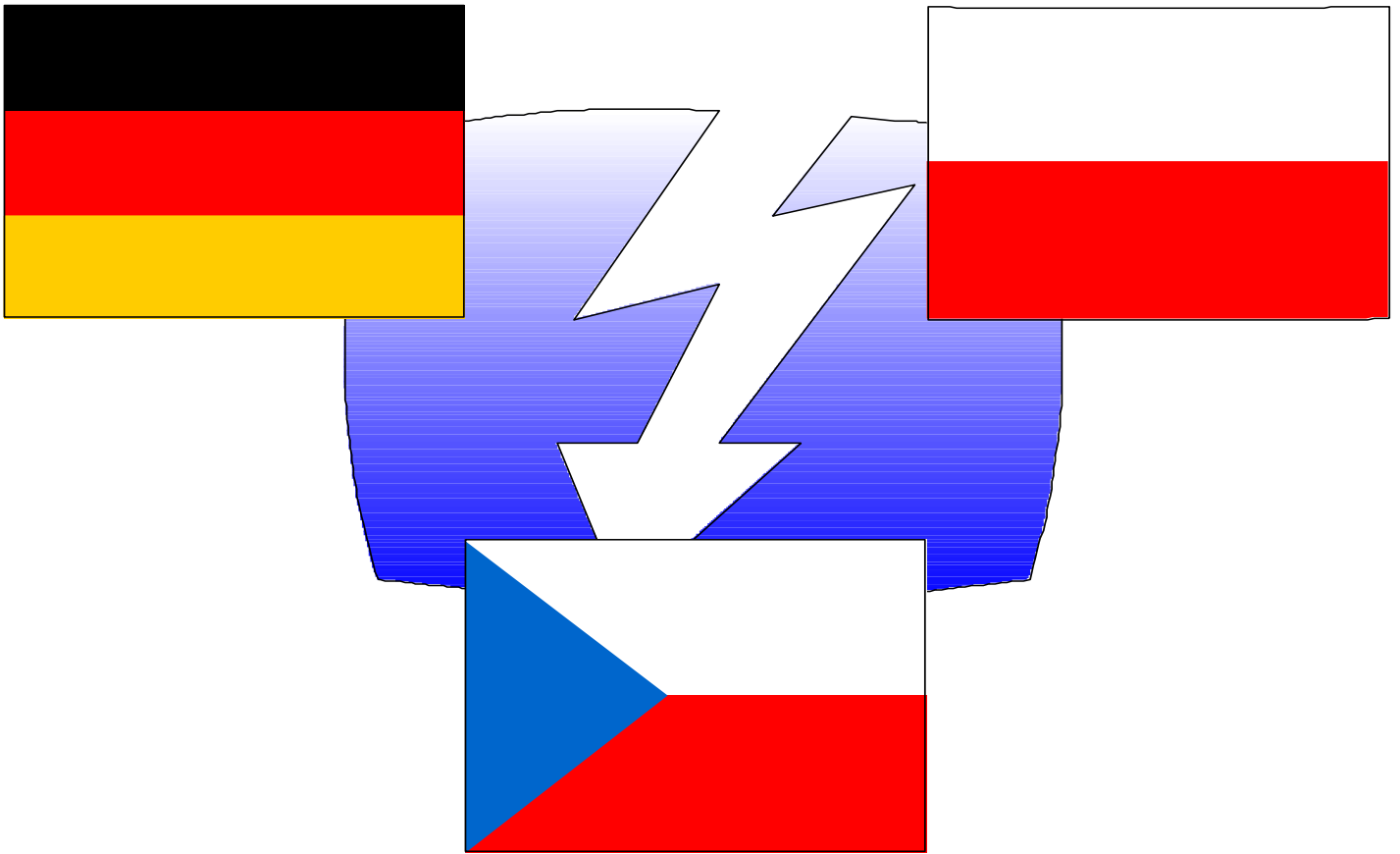


Internationale Elektrotechnik - Olympiade



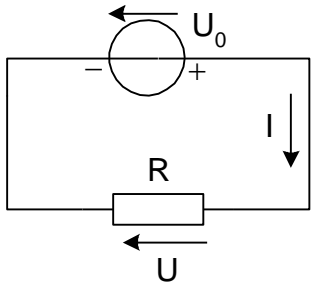
NEISSE – ELEKTRO

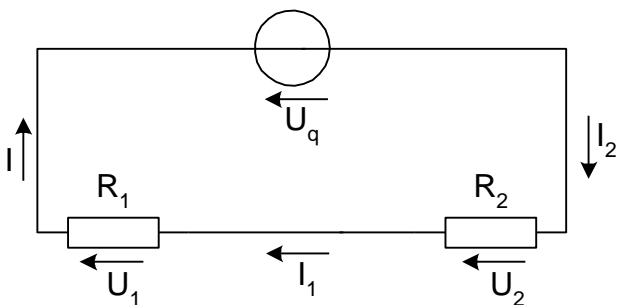
Formulas

english edition

version 2023-03

Simple Circuit

electrical voltage U	$U = \varphi_1 - \varphi_2$	<p>φ_1 electrical potential of point 1 φ_2 electrical potential of point 2 Q electric charge t time</p>  <p>U_0 voltage of the voltage source</p>
electrical current I	$I = \frac{dQ}{dt}$ under the condition of a stationary current ($I = \text{constant}$) apply to: $I = \frac{Q}{t}$	
current density S	$S = \frac{I}{A}$	
electrical resistor R	$R = \frac{U}{I}$	
electrical conductance G	$G = \frac{1}{R}$	
electrical power P	$P = U \cdot I$	
electrical work W	$W = P \cdot t$	
OHM's law	under the condition $\vartheta = \text{constant}$ apply to: $U \sim I, \frac{U}{I} = \text{constant}$	
assessment of resistor	under the condition $\vartheta = \text{constant}$ apply to: $R = \frac{\rho \cdot l}{A}$	
electrical conductivity γ (κ)	$\gamma = \frac{1}{\rho}$	
influence of the temperature on the electrical resistor	$\Delta R = \alpha \cdot R_{20} \cdot \Delta\vartheta$ with $\Delta\vartheta = \vartheta - 20^\circ\text{C}$ $R_\vartheta = R_{20} (1 + \alpha \cdot \Delta\vartheta)$	<p>ϑ temperature ρ specific electrical resistance l length of the conductor A cross-section area R_ϑ resistor by the temperature ϑ R_{20} resistor by 20°C α temperature coefficient</p>

Direct current circuits**Series connection of resistors**

$$I = I_1 = I_2 = \dots = I_n$$

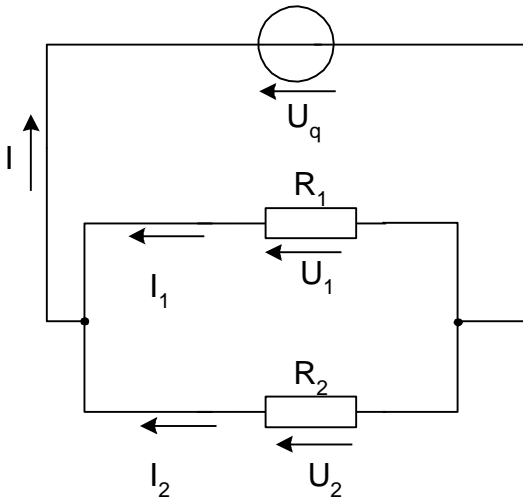
$$U_q = U_1 + U_2 + \dots + U_n$$

$$R = R_1 + R_2 + \dots + R_n$$

potential divider rule:

$$\frac{U_1}{U_2} = \frac{R_1}{R_2} \quad \frac{U_1}{U_q} = \frac{R_1}{R}$$

Parallel connection of resistors



$$I = I_1 + I_2 + \dots + I_n$$

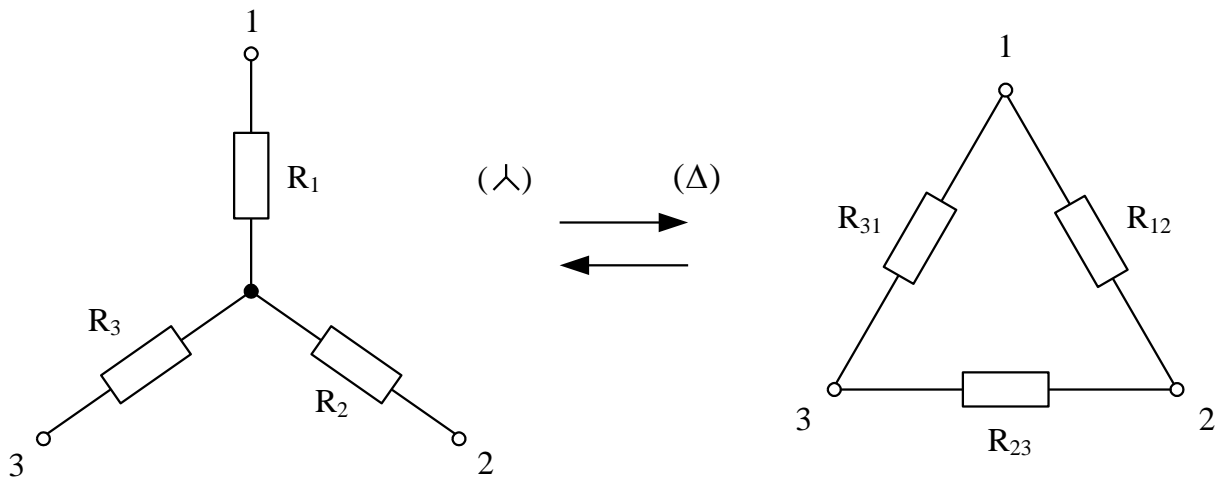
$$U_q = U_1 = U_2 = \dots = U_n$$

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \dots + \frac{1}{R_n}$$

current divider rule:

$$\frac{I_1}{I_2} = \frac{R_2}{R_1} \quad \frac{I_1}{I} = \frac{R}{R_1}$$

Network transformation



Transformation $Y \rightarrow \Delta$

$$R_{12} = R_1 + R_2 + \frac{R_1 R_2}{R_3}$$

$$R_{23} = R_2 + R_3 + \frac{R_2 R_3}{R_1}$$

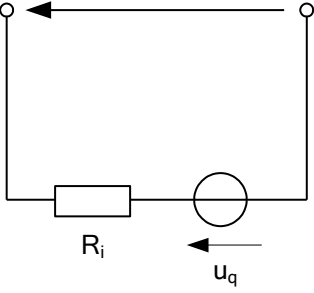
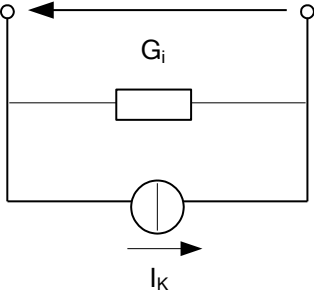
$$R_{31} = R_3 + R_1 + \frac{R_3 R_1}{R_2}$$

Transformation $\Delta \rightarrow Y$

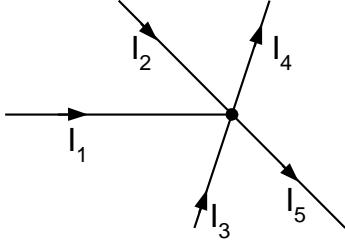
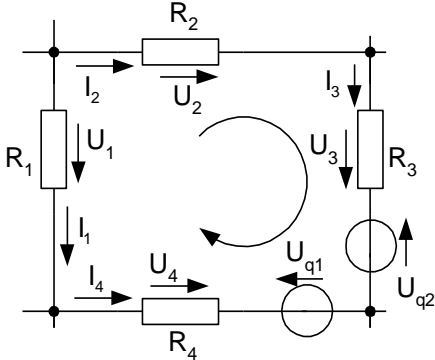
$$R_1 = \frac{R_{12} R_{31}}{R_{12} + R_{23} + R_{31}}$$

$$R_2 = \frac{R_{23} R_{12}}{R_{12} + R_{23} + R_{31}}$$

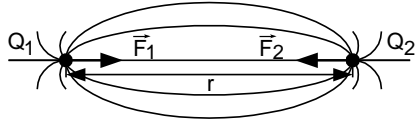
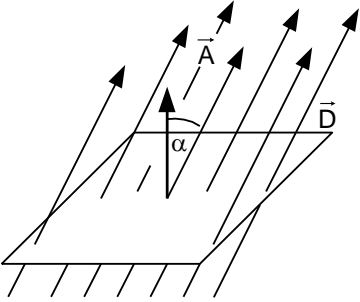
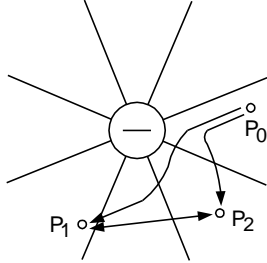
$$R_3 = \frac{R_{31} R_{23}}{R_{12} + R_{23} + R_{31}}$$

Series connection of voltage sources	Parallel connection of voltage sources
$U = \sum U_q$ $R_i = \sum R_i$	$I_K = \sum I_K$ $G_i = \sum G_i$
	

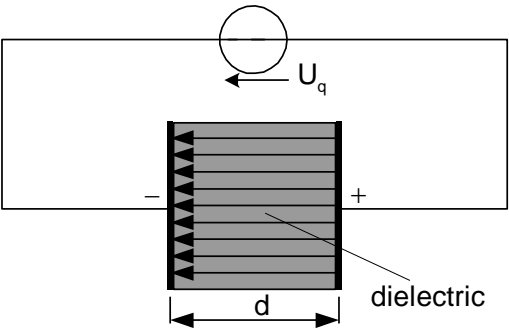
$$R_i = \frac{U_q}{I_K} \qquad R_i = \frac{1}{G_i}$$

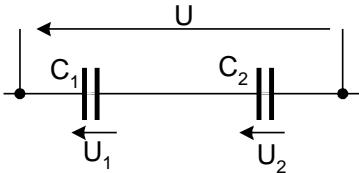
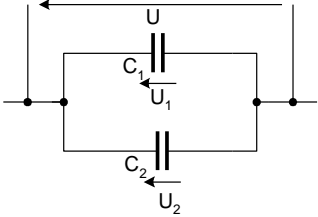
1. KIRCHHOFF's law (Junction law)	2. KIRCHHOFF's law (Meshwork law)
 $-I_1 - I_2 - I_3 + I_4 + I_5 = 0$	 $-U_1 + U_2 + U_3 - U_{q2} + U_{q1} - U_4 = 0$
$\sum_{k=1}^n I_k = 0$	$\sum_{i=1}^n U_i + \sum_{k=1}^m U_{qk} = 0$

Electrical field

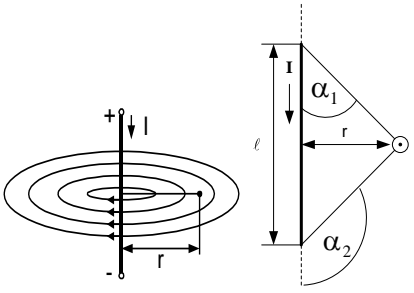
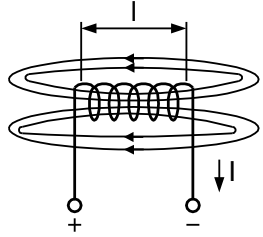
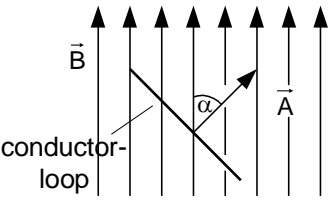
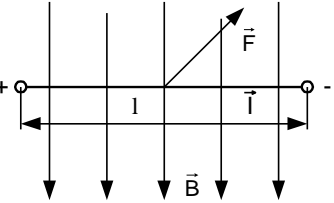
electrical charge Q	$Q = N \cdot e$ $Q = \int_{t_1}^t I(t) dt$	N number of electrons e elementary charge (p. 14) I current intensity t time F force
COULOMB's law	for point charges, apply to: $F = \frac{1}{4\pi \cdot \epsilon_0 \cdot \epsilon_r} \frac{Q_1 \cdot Q_2}{r^2}$	ϵ_0 permittivity (vacuum) (p. 14) ϵ_r dielectric constant r distance between the point charges
electrical field strength E	$\vec{E} = \frac{\vec{F}}{Q}$ for homogeneous electric field, apply to: $E = \frac{U}{s}$	 s distance between the points, which have the voltage drop U
electrical flux density D	$\vec{D} = \epsilon_0 \cdot \epsilon_r \cdot \vec{E}$ for vacuum apply to: $\epsilon_r = 1$	
dielectric constant ϵ	$\epsilon = \epsilon_0 \cdot \epsilon_r$	
electrical flux Ψ	$\Psi = \int \vec{D} d\vec{A}$ under the condition $\vec{D} = \text{constant und } \vec{D} \parallel \vec{A}$ apply to: $\Psi = D \cdot A$	A area
electrical potential φ	$\varphi = \frac{W}{Q} \quad \varphi = \int_{P_0}^{P_1} \vec{E}(s) d\vec{s}$	
electrical voltage U	$U = \varphi_1 - \varphi_2 \quad U = \int_{P_2}^{P_1} \vec{E}(s) d\vec{s}$ for homogeneous field, apply to: $U = \vec{E} \cdot \vec{s}$	W dislocation work on a charge Q in the electrical field φ_1 electrical potential in point P ₁ φ_2 electrical potential in point P ₂ s distance

Capacitors

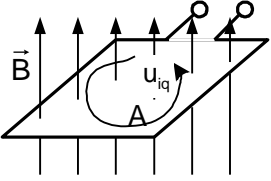
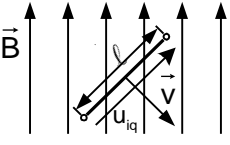
capacitance C of an capacitor	$C = \frac{Q}{U}$	 <p> Q charge U voltage d distance between the plates ϵ_0 permittivity (vacuum) (p. 14) ϵ_r dielectric constant A area </p>
breakdown strength E_d	$E_d = \frac{U}{d}$	
electrical strength of field E of an plate capacitor	$E = \frac{U}{d}$	
capacitance C of an plate capacitor	$C = \epsilon_0 \cdot \epsilon_r \cdot \frac{A}{d}$	
capacitance C of an cylindrical capacitor	$C = \frac{2\pi \cdot \epsilon_0 \cdot \epsilon_r \cdot \ell}{\ln \frac{r_a}{r_i}}$	
energy E of the electric field (plate capacitor)	$E = \frac{1}{2} C \cdot U^2$	
charge of an capacitor	$U_C = U \cdot \left(1 - e^{\left(-\frac{t}{R \cdot C} \right)} \right)$ $I = I_0 \cdot e^{\left(-\frac{t}{R \cdot C} \right)}$	U_C capacitor-voltage U charging voltage R OHM's resistor C capacitor t time I current intensity I_0 current intensity ($t = 0$) e EULER's number
discharge of an capacitor	$U_C = U \cdot e^{\left(-\frac{t}{R \cdot C} \right)}$ $I = I_0 \cdot e^{\left(-\frac{t}{R \cdot C} \right)}$	
time constant τ	$\tau = R \cdot C$	

Series connection of capacitors	Parallel connection of capacitors
 $\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \dots + \frac{1}{C_n}$	 $C = C_1 + C_2 + \dots + C_n$
$U = U_1 + U_2 + \dots + U_n$	$U = U_1 = U_2 = \dots = U_n$

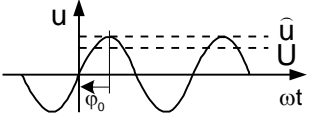
Magnetic field

magnetic strength of field H	<p>for the field outside of an direct conductor with the current I, apply to:</p> $H = \frac{I}{2\pi r}$ $H = \frac{I}{4\pi \cdot r} (\cos \alpha_1 - \cos \alpha_2)$ <p>for the field inside of an long coil with the current I, apply to:</p> $H = \frac{N \cdot I}{l}$ <p>for homogeneous magnetic field, apply to:</p> $H = \frac{\Theta}{s}$	<p>I current density r distance from conductor</p>  <p>N winding number of the coil l length of the coil</p>
magnetic flux density B (magnetic induction)	$\vec{B} = \mu_0 \cdot \mu_r \cdot \vec{H}$	
permeability μ	$\mu = \mu_0 \cdot \mu_r$ <p>for vacuum, apply to: $\mu_r = 1$</p>	
magnetic flux Φ	$\Phi = \int \vec{B} \cdot d\vec{A}$ <p>for $\vec{B} = \text{constant}$ and $\vec{B} \parallel \vec{A}$ apply to:</p> $\Phi = B \cdot A$	<p>Θ magnetomotive force s circle of an area μ_0 permittivity (vacuum, p.14) μ_r permeability A area</p>
magnetic Voltage V	$V = \int_{P_1}^{P_2} \vec{H}(s) \cdot d\vec{s}$ <p>under the condition of homogeneous field, apply to:</p> $V = \vec{H} \cdot \vec{s}$	
magnetic resistor R_m	$R_m = \frac{l}{\mu_0 \cdot \mu_r \cdot A}$ $R_m = \frac{V}{\Phi}$	<p>s distance l length A area Q charge v speed l length of the conductor</p>
force of an moved electron F_L (LORENTZ's force)	$\vec{F}_L = Q \cdot \vec{v} \times \vec{B}$ <p>under the condition $\vec{v} \perp \vec{B}$ apply to:</p> $F_L = Q \cdot v \cdot B$	
force F to a conductor with current I	$\vec{F} = I \cdot \vec{l} \times \vec{B}$ <p>under the condition $\vec{l} \perp \vec{B}$ apply to:</p> $F = I \cdot l \cdot B$	
energy E of the magnetic field of a coil with current I	$E = \frac{1}{2} L \cdot I^2$	<p>L inductivity of the coil</p>

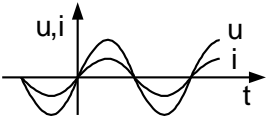
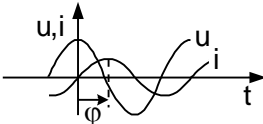
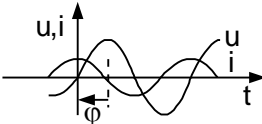
Electromagnetic field

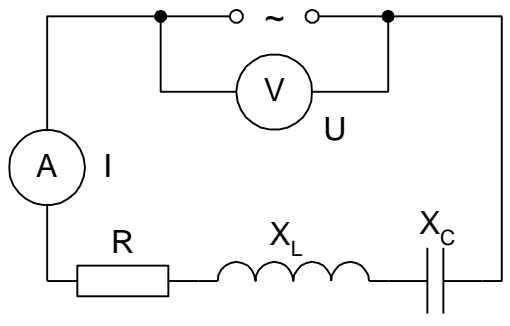
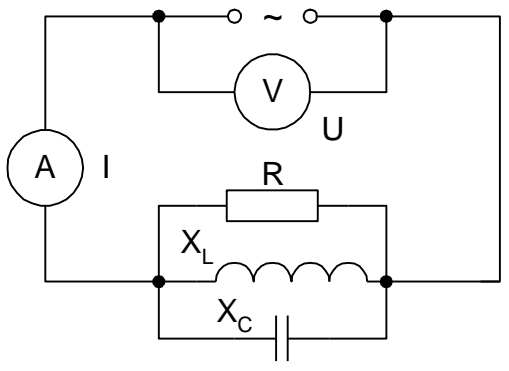
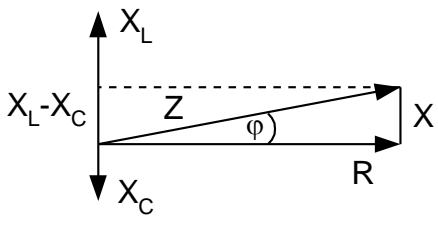
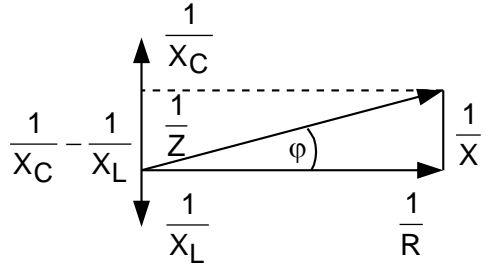
<p>Induction law</p>	$u_{iq} = \frac{d\Phi}{dt}$ <p>under the condition of steady change of the magnetic field and $\vec{B} \perp \vec{A}$ for a coil, apply to:</p> $u_{iq} = N \frac{\Delta(B \cdot A)}{\Delta t}$ <p>for an moved conductor $\vec{v} \perp \vec{B}$ apply to:</p> $u_{iq} = v \cdot B \cdot \ell$	<p>U_i induced voltage Φ magnetic flux N number of windings t time B magnetic flux density A area</p> 
<p>self-induced voltage in a coil</p>	$u = L \cdot \frac{di}{dt}$ <p>under the condition of steady change of the current, apply to:</p> $u = L \cdot \frac{\Delta I}{\Delta t}$	<p>v speed of the conductor ℓ length of the conductor or the coil</p> 
<p>inductivity L of an coil</p>	<p>for an long coil, apply to:</p> $L = \frac{\mu_0 \cdot \mu_r \cdot N^2 \cdot A}{l}$	<p>I current intensity μ_0 permittivity (vacuum, p.14) μ_r permeability A area</p>

Alternating current circuit

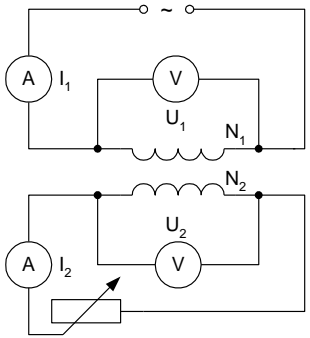
<p>current i in alternating current circuit</p>	<p>momentary value: $i = \hat{i} \cdot \sin(\omega \cdot t + \varphi_0)$ root-mean-square value: $I = \frac{1}{\sqrt{2}} \hat{i} \approx 0,7 \hat{i}$</p>	<p>ω angular frequency i momentary value t time \hat{i} peak value I root-mean-square value</p>
<p>voltage u in alternating current circuit</p>	<p>momentary value: $u = \hat{u} \cdot \cos(\omega t + \varphi_0)$ root-mean-square value: $U = \frac{1}{\sqrt{2}} \hat{u} \approx 0,7 \hat{u}$</p>	<p>φ_0 lag angle u momentary value \hat{u} peak value U root-mean-square value</p>
<p>apparent power S</p>	$S = U \cdot I$	
<p>effective power P</p>	$P = U \cdot I \cdot \cos \varphi$	<p>$\cos \varphi$ power factor φ lag angle</p>
<p>reactive power Q</p>	$Q = U \cdot I \cdot \sin \varphi$	

Resistors in alternating current circuit

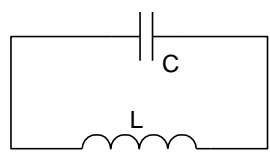
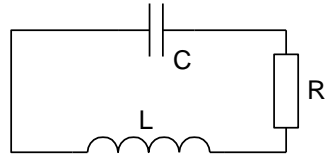
OHM's resistor R $R = \frac{U}{I}$	resistance of inductivity X_L $X_L = \frac{U}{I}$	resistance of capacitor X_C $X_C = \frac{U}{I}$
for a metallic conductor under the condition $\vartheta = \text{constant}$, apply to: $R = \frac{\rho \cdot l}{A}$	for a coil, apply to: $X_L = \omega \cdot L$	for a capacitor, apply to: $X_C = \frac{1}{\omega \cdot C}$
		

Series connection of R, X_L and X_C		Parallel connection of R, X_L and X_C	
circuit 		circuit 	
phasor diagram 		phasor diagram 	
reactive resistance X (reactance)	$X = \omega \cdot L - \frac{1}{\omega \cdot C}$	$\frac{1}{X} = \omega \cdot C - \frac{1}{\omega \cdot L}$	
apparent resistance Z (impedance)	$Z = \sqrt{R^2 + X^2}$	$\frac{1}{Z} = \sqrt{\frac{1}{R^2} + \frac{1}{X^2}}$	
lag $\tan \varphi$	$\tan \varphi = \frac{X_L - X_C}{R}$	$\tan \varphi = R \left(\frac{1}{X_C} - \frac{1}{X_L} \right)$	

Transformation

voltage transformation for an transformer without losses	under the condition $I_2 \rightarrow 0$ (no-load), apply to: $\frac{U_1}{U_2} = \frac{N_1}{N_2}$	 <p>U voltage I current N number of windings P power P_v power loss φ lag angle between current and voltage P_{out} power output P_{in} power input</p>
current transformation for an transformer without losses	under the condition $I_2 \rightarrow \infty$ (short), apply to: $\frac{I_1}{I_2} = \frac{N_2}{N_1}$	
transformation ratio \ddot{u}	$\ddot{u} = \frac{N_1}{N_2}$	
power transformation	$P_1 = P_2 + P_v$ $U_1 \cdot I_1 \cdot \cos \varphi_1 = U_2 \cdot I_2 \cdot \cos \varphi_2 + P_v$ under the conditions of heavy load, without losses and $\varphi_1 = \varphi_2$ apply to: $U_1 \cdot I_1 = U_2 \cdot I_2$	
effectiveness η of an transformer	$\eta = \frac{P_{out}}{P_{in}}$	

Electromagnetic oscillation

THOMSON's oscillation law	$T = 2\pi \cdot \sqrt{L \cdot C}$	T period L inductivity C capacity
frequency f of an electrical oscillating circuit (without attenuation)	under the condition of a free oscillation without attenuation ($R=0$), apply to: $f = \frac{1}{2\pi\sqrt{L \cdot C}}$	
natural frequency f of an electrical oscillating circuit (with attenuation)	under the condition of a free oscillation, apply to: $f = \frac{1}{2\pi} \sqrt{\frac{1}{L \cdot C} - \frac{R^2}{4L^2}}$	R OHM's resistor L inductivity C capacity
damping coefficient δ	$\delta = \frac{R}{2L}$	 f natural frequency f_e exciter frequency
resonance condition	$f = f_e$	

Characteristics and units

characteristik	symbol	unit	Conversion between the units
damping coefficient	δ	per second	s^{-1} $1 s^{-1} = 60 \text{ min}^{-1}$
work	W, A	joule newtonmeter watt-second kilowatt-hour	J $N \cdot m$ $W \cdot s$ $kW \cdot h$ $1 J = 1 \text{ kg} \cdot \text{m}^2 \cdot \text{s}^{-2}$ $= 1 N \cdot m$ $= 1 W \cdot s$ $1 kW \cdot h = 3,6 \cdot 10^6 W \cdot s$
illuminance	E	lux	lx $1 \text{ lx} = 1 \text{ lm} \cdot \text{m}^{-2}$
acceleration	a, g	meter per square-second	$m \cdot s^{-2}$ $1 m \cdot s^{-2} = 1 N \cdot \text{kg}^{-1}$
reactive power	Q	voltampere reactive	VAr $1 \text{ VAr} = 1 \text{ var}$
density (of aggregate)	ρ	kilogramme per cubic meter gramme per cubic centimeter	$\text{kg} \cdot \text{m}^{-3}$ $\text{g} \cdot \text{cm}^{-3}$ $1 \text{ kg} \cdot \text{m}^{-3} = 10^{-3} \text{ g} \cdot \text{cm}^{-3}$ $1 \text{ g} \cdot \text{cm}^{-3} = 10^3 \text{ kg} \cdot \text{m}^{-3}$
torque	M	newtonmeter	$N \cdot m$ $1 N \cdot m = 1 \text{ kg} \cdot \text{m}^2 \cdot \text{s}^{-2}$
speed (rate of revolutions)	n	per second	s^{-1} $1 s^{-1} = 60 \text{ min}^{-1}$
magnetomotive force	Θ	ampere	A
breakdown strength	E_d	volt per meter	$V \cdot \text{m}^{-1}$
energy	W	joule newtonmeter watt-second electron volt	J $N \cdot m$ $W \cdot s$ eV $1 J = 1 \text{ kg} \cdot \text{m}^2 \cdot \text{s}^{-2}$ $= 1 N \cdot m$ $= 1 W \cdot s$ $1 \text{ eV} = 1,602 \cdot 10^{-19} \text{ J}$
gravitational acceleration	g	meter per square-second	$m \cdot s^{-1}$ $1 m \cdot s^{-1} = 1 N \cdot \text{kg}^{-1}$
electrical field strength	E	volt per meter	$V \cdot \text{m}^{-1}$ $1 V \cdot \text{m}^{-1} = 1 \text{ kg} \cdot \text{m} \cdot \text{s}^{-3} \cdot \text{V}^{-1}$
electrical flux	ψ	coulomb	C $1 C = 1 A \cdot s$
magnetical flux	ϕ	weber	Wb $1 \text{ Wb} = 1 V \cdot s$
magnetical flux density (magnetic induction)	B	tesla	T $1 T = 1 \text{ Wb} \cdot \text{m}^{-2}$ $= 1 V \cdot s \cdot \text{m}^{-2}$ $= 1 N \cdot \text{m}^{-1} \cdot A^{-1}$

characteristic	symbol	unit	Conversion between the units
frequency	f	hertz Hz	1 Hz = 1 s ⁻¹
speed (propagation speed)	v c	meter per second kilometer per hour knot m · s ⁻¹ km · h ⁻¹ kn	1 m · s ⁻¹ = 3,6 km · h ⁻¹ 1 km · h ⁻¹ = 0,28 m · s ⁻¹ 1 kn = 1 sm · h ⁻¹ = 1852 m · h ⁻¹
inductivity	L	henry H	1 H = 1 Wb · A ⁻¹ = 1 m ² · kg · s ⁻² · A ⁻²
capacity	C	farad F	1 F = 1 A · s · V ⁻¹
force	F	newton kilopond N kp	1 N = 1 kg · m · s ⁻² = 1 J · m ⁻¹ 1 kp = 9,81 N
angular frequency	ω	per second s ⁻¹	1 s ⁻¹ = 60 min ⁻¹
electrical charge	Q	coulomb C	1 C = 1 A · s
power	P	watt W	1 W = 1 J · s ⁻¹ = 1 V · A = 1 kg · m ² · s ⁻³ = 1 N · m · s ⁻¹
power factor	cos φ	1	
electrical conductivity	γ	siemens per meter S · m ⁻¹	1 S · m ⁻¹ = 1 Ω ⁻¹ · m ⁻¹ = 10 ⁻⁶ m · Ω ⁻¹ · mm ⁻²
electrical conductance	G	siemens S	1 S = 1 Ω ⁻¹
light density	L	candela per square-meter cd · m ⁻²	
period (of oscillation)	T	second s	mentioned below (time)
electrical potential	φ	volt V	
electrical voltage (potential difference)	U, u	volt V	1 V = 1 kg · m ² · s ⁻³ · A ⁻¹
magnetic voltage	V	ampere A	1 A = 1 J · Wb ⁻¹

characteristic	symbol	unit	Conversion between the units
current	I, i	ampere A	1 A = $1 \text{ kg} \cdot \text{m}^2 \cdot \text{s}^{-3} \cdot \text{V}^{-1}$
heat (heat quantity)	Q	joule J	1 J = $1 \text{ N} \cdot \text{m}$ = $1 \text{ kg} \cdot \text{m}^2 \cdot \text{s}^{-2}$ = $1 \text{ W} \cdot \text{s}$
		kalorie cal	1 cal = 4,19 J
heat capacity	C_{th}	joule per kelvin $\text{J} \cdot \text{K}^{-1}$	
heat conduction resistor	R_{λ}	kelvin per watt $\text{K} \cdot \text{W}^{-1}$	
heat current	Φ_{th}	watt W	1 W = $1 \text{ J} \cdot \text{s}^{-1}$
OHM's resistor	R	ohm Ω	1 Ω = $1 \text{ V} \cdot \text{A}^{-1}$ = 1 S^{-1}
resistance of inductivity	X_L	ohm Ω	1 Ω = $1 \text{ V} \cdot \text{A}^{-1}$
resistance of capacitor	X_C	ohm Ω	1 Ω = $1 \text{ V} \cdot \text{A}^{-1}$
magnetic resistor	R_m	per henry H^{-1}	1 H^{-1} = $1 \text{ A} \cdot \text{Wb}^{-1}$
angle	$\alpha, \beta,$	radiant rad	1 rad = $\frac{180^\circ}{\pi} \approx 57,296^\circ$
	$\gamma, \varphi, \sigma ..$	degree of angle $^\circ$	1 $^\circ$ = $\frac{\pi}{180} \text{ rad} \approx 0,01745 \text{ rad}$
angular acceleration	α	per square-second s^{-2}	1 s^{-2} = $3600 \cdot \text{min}^{-2}$ = $1 \text{ rad} \cdot \text{s}^{-2}$
angular speed	ω	per second s^{-1}	1 s^{-1} = 60 min^{-1} = $1 \text{ rad} \cdot \text{s}^{-1}$
efficiency	η		1 or %
time (span, term)	t	second s	
		minute min	1 min = 60 s
		hour h	1 h = 60 min = 3600 s
		day d	1 d = 24 h = 1440 min = 86400 s
year a	1 a = 365 d or 366 d		

Physical constants

constant	symbol	value and unit
permittivity (vacuum)	ϵ_0	$8,854 \cdot 10^{-12} \text{ A}\cdot\text{s}/\text{V}\cdot\text{m}$
permeability (vacuum)	μ_0	$1,257 \cdot 10^{-6} \text{ V}\cdot\text{s}/\text{A}\cdot\text{m}$
elementary charge	e	$1,6021 \cdot 10^{-19} \text{ C}$
speed of light (vacuum)	c_0	$2,99792 \cdot 10^8 \text{ m/s}$
electron mass (at rest)	m_e	$9,109 \cdot 10^{-28} \text{ g}$
proton mass (at rest)	m_p	$1,6725 \cdot 10^{-24} \text{ g}$
neutron mass (at rest)	m_n	$1,6748 \cdot 10^{-24} \text{ g}$
Boltzmann constant	k	$1,381 \cdot 10^{-23} \text{ J/K}$
Planck constant	h	$6,626 \cdot 10^{-34} \text{ J}\cdot\text{s}$
gravitational constant	G	$6,673 \cdot 10^{-11} \text{ m}^3 / (\text{kg}\cdot\text{s}^2)$
gravitational acceleration	g	$9,80665 \text{ m/s}^2$
absolute zero of thermodynamical temperature	T_0	$-273,15 \text{ }^\circ\text{C}$
Loschmidt number	L	$6,023 \cdot 10^{23} \text{ molecules/mol}$