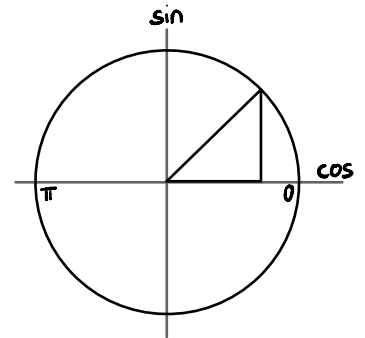


Experimentalphysik SS22

Formelsammlung - Jakob Werner

Grundlagen

$^\circ$	0	30	45	60	90	120	135	150	180
π	0	$\frac{\pi}{6}$	$\frac{\pi}{4}$	$\frac{\pi}{3}$	$\frac{\pi}{2}$	$\frac{2\pi}{3}$	$\frac{3\pi}{4}$	$\frac{5\pi}{6}$	π
sin	0	$\frac{1}{2}$	$\frac{\sqrt{2}}{2}$	$\frac{\sqrt{3}}{2}$	1	$\frac{\sqrt{3}}{2}$	$\frac{\sqrt{2}}{2}$	$\frac{1}{2}$	0
cos	1	$\frac{\sqrt{3}}{2}$	$\frac{\sqrt{2}}{2}$	$\frac{1}{2}$	0	$-\frac{1}{2}$	$-\frac{\sqrt{2}}{2}$	$-\frac{\sqrt{3}}{2}$	-1
tan	0	$\frac{\sqrt{3}}{3}$	1	$\sqrt{3}$	$\pm\infty$	$-\sqrt{3}$	-1	$-\frac{\sqrt{3}}{3}$	0



Potenzrechnen

$$a^n \pm b^n \neq (a \pm b)^n$$

$$a^n \cdot b^n = (a \cdot b)^n, \quad a^n \cdot a^m = a^{n+m}$$

$$\frac{a^n}{b^n} = \left(\frac{a}{b}\right)^n, \quad \frac{a^n}{a^m} = a^{n-m}$$

$$(a^n)^m = a^{n \cdot m}$$

$$a^{-n} = \frac{1}{a^n}, \quad a^{\frac{1}{n}} = \sqrt[n]{a}$$

Wurzelrechnen

$$\sqrt{a} \pm \sqrt{b} \neq \sqrt{a \pm b}$$

$$\sqrt{a} \cdot \sqrt{b} = \sqrt{a \cdot b}$$

$$\frac{\sqrt{a}}{\sqrt{b}} = \sqrt{\frac{a}{b}}$$

$$\sqrt[n]{a^b} = (\sqrt[n]{a})^b$$

Wichtige Ableitungen

$$x^n \rightarrow n \cdot x^{n-1}$$

$$\frac{1}{x} \rightarrow -\frac{1}{x^2}$$

$$\frac{1}{x^n} = x^{-n} \rightarrow -\frac{n}{x^{n+1}}$$

$$\sqrt{x} = x^{\frac{1}{2}} \rightarrow \frac{1}{2\sqrt{x}}$$

$$\tan(x) \rightarrow \frac{1}{\cos^2(x)}$$

$$\ln(x) \rightarrow \frac{1}{x}$$

Wichtige Stammfunkt.

$$x \rightarrow \frac{1}{2} x^2$$

$$x^n \rightarrow \frac{1}{n+1} x^{n+1}$$

$$\frac{1}{x} \rightarrow \ln|x|$$

$$\frac{1}{x^n} = x^{-n} \rightarrow \frac{-1}{(n-1)x^{n-1}}$$

$$\sqrt{x} = x^{\frac{1}{2}} \rightarrow \frac{2}{3} x^{\frac{3}{2}}$$

Logarithmen

$$\log(a \cdot b) = \log(a) + \log(b)$$

$$\log\left(\frac{a}{b}\right) = \log(a) - \log(b)$$

$$\log(a^n) = n \cdot \log(a)$$

binom. Formeln

$$(a \pm b)^2 = a^2 \pm 2ab + b^2$$

$$(a+b) \cdot (a-b) = a^2 - b^2$$

Vektoren:

$$\cos \alpha = \frac{\langle v_1 | v_2 \rangle}{|v_1| |v_2|}, \quad 0 \leq \alpha \leq \pi$$

$$a \times b = \begin{pmatrix} a_2 b_3 - a_3 b_2 \\ a_3 b_1 - a_1 b_3 \\ a_1 b_2 - a_2 b_1 \end{pmatrix}$$

$$b \times a = -a \times b, \quad a \times (sb) = s(a \times b)$$

$$|a \times b| = |a| |b| \cdot \sin \varphi(a, b)$$

Potenzen:

h	k	M	G	T
10^2	10^3	10^6	10^9	10^{12}

d	c	m	μ	n	p
10^{-1}	10^{-2}	10^{-3}	10^{-6}	10^{-9}	10^{-12}

Elektrostatik

Elektr. Ladung, Kräfte, Feld

Coulombgesetz $F_c = \frac{1}{4\pi\epsilon_0} \cdot \frac{q_1 \cdot q_2}{r^2}$

$$F_{q_2 \rightarrow q_1}^c = -F_{q_1 \rightarrow q_2}^c$$

elektr. Feld/Kraft $\vec{F}(\vec{r}) = Q \cdot \vec{E}(\vec{r})$

Satz von Gauß

el. Fluss $\Phi = \vec{E} \cdot \vec{A} = \frac{Q}{\epsilon_0}$

Kugelsymmetr. Ldg.verteilung $E(r) = \frac{1}{4\pi\epsilon_0} \cdot \frac{Q}{r^2}$

langer, gerader Draht $E(r) = \frac{1}{2\pi\epsilon_0} \cdot \frac{\lambda}{r}$

λ = Linienladungsdichte

unendliche Platte $E = \frac{\sigma}{2\epsilon_0}$

σ = Flächenladungsdichte

Plattenkondensator $E = \frac{\sigma}{\epsilon_0}$

Elektrostatistisches Potential / El. Spannung

Definition $W(\vec{r}) = q \cdot \varphi_{el}(\vec{r})$, $\Delta\varphi_{el} = U$

$$W_{el} = \frac{1}{2} \epsilon_0 \vec{E}^2(\vec{r}) (\cdot V)$$

Plattenkond. $U = E \cdot d$, $C = \frac{Q}{U} = \frac{\epsilon_0 \cdot A}{d}$

$$E_{pot} = \frac{1}{2} \frac{Q^2}{C} = \frac{1}{2} C \cdot U^2 = W$$

Punktladung $\varphi_{el}(\vec{r}) = \frac{Q}{4\pi\epsilon_0 r}$

Materie im el. Feld

Elektr. Leiter $I = \frac{dQ}{dt}$

Stromdichte $\vec{j} = \frac{I}{A} \cdot \hat{n}$ $\hat{n}$ = Richtung des pos. Strom

OG $\vec{j} = \sigma \cdot \vec{E}$ σ = Leitfähigkeit (Material)

$$U = R \cdot I$$

Leistung $P = U \cdot I = R \cdot I^2 = \frac{U^2}{R}$

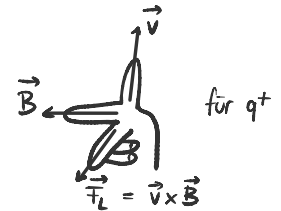
Braun'sche Röhre $v = \sqrt{\frac{2eU}{m}}$

Isolatoren + Dipole	Dipol	$\vec{p} = q \cdot \vec{d}$	von $\ominus$ nach $\oplus$
	hom. el. Feld	$\vec{M} = \vec{p} \times \vec{E}$	, $U = -\vec{p} \cdot \vec{E}_{\text{ext}}$
	inhom. Feld	$F = p \cdot \frac{dE}{dx}$	
Dielektrizität		$\vec{D} = \epsilon_0 \cdot \vec{E} + \vec{P} = \epsilon_0 \cdot \epsilon_r \cdot \vec{E}$	

Magnetostatik

Lorentzkraft

$$\vec{F}_L = q \cdot \vec{v} \times \vec{B} \quad B = \frac{F}{q \cdot v}$$



Trajektorien

$$\vec{v} \perp \vec{B} : \quad r = \frac{m}{q} \cdot \frac{v}{B}$$

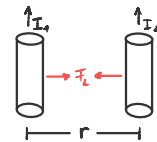
el. Leiter

Länge d

$$\vec{F}_L = I \cdot \vec{d} \times \vec{B}$$

parallele Leiter

$$F_L = \frac{\mu_0}{2\pi} \cdot \frac{I_1 \cdot I_2 \cdot d}{r}$$



Hall-Effekt

$$U_H = \frac{I \cdot B}{e \cdot n \cdot d} \quad (n = e^- \text{-Dichte}, \quad d = \text{Dicke})$$

Ampèresches Durchflutungsprinzip

Durchflutungsgesetz

$$\oint \vec{B} \cdot d\vec{r} = \mu_0 \cdot I$$

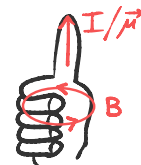
gerader Leiter

$$B(r) = \frac{\mu_0}{2\pi} \cdot \frac{I}{r}$$

Kreisstrom

Dipol

$$\vec{\mu} = I \cdot \vec{A}$$



Energie

$$U = -\vec{\mu} \cdot \vec{B}$$

Drehmoment

$$\vec{M} = \vec{\mu} \times \vec{B}$$



Spule

$$B = \mu_0 \cdot \frac{N \cdot I}{d}$$

Energie

$$W_{\text{magn}} = \frac{1}{2} \cdot \frac{B^2}{\mu_0 \cdot \mu_r}$$

$$W_{\text{Spule}} = \frac{1}{2} \mu_0 \frac{N^2 \cdot A}{d} \cdot I^2$$

Magnetismus in Materie

magn. Feldstärke

$$\vec{H} = \frac{\vec{B}}{\mu_0 \mu_r}$$

$\mu_r \approx 1$: Diamagn. , $\mu_r \approx 1$: Paramagn. , $\mu_r \gg 1$: Ferromagn.

Elektrodynamik

Zsh. $E(t) - B(t)$ $\vec{E}' = \vec{v} \times \vec{B}$, $\vec{B}' = -\frac{1}{c^2} \vec{v} \times \vec{E}$

Induktion

Elektr. Felder $U_{\text{ind}} = - \frac{d}{dt} \phi_m$ (der Ursache entgegen)

Dynamo $U_{\text{ind}} = U_0 \cdot \sin(\omega t)$ $U_0 = N \cdot B \cdot A \cdot \omega$

Selbstinduktion $U_{\text{ind}} = -L \cdot \frac{dI}{dt}$ $L = \mu_0 \cdot \frac{N^2 \cdot A}{l}$

$$E_{\text{pot}} = \frac{1}{2} \cdot L \cdot I^2$$

Elektronik

Passive Bauelemente und Wechselstrom

Widerstand $U_{\text{eff}} = \frac{1}{\sqrt{2}} U_0$ $I_{\text{eff}} = \frac{1}{\sqrt{2}} I_0$

$$P_{\text{eff}} = \frac{1}{2} U_0 \cdot I_0 = \frac{1}{2} \frac{U_0^2}{R} = \frac{1}{2} R \cdot I_0^2$$

Kondensator $R_c(\omega) = \frac{U_0}{I_0} = \frac{1}{\omega \cdot C}$ $Z = \frac{1}{i\omega C}$

Spule $R_L(\omega) = \omega L$ $Z = i\omega L$

Elektr. Netzwerke

KH'sche Ges. Knotenregel $\sum_{j=1}^N I_j = 0$ Ladungserhaltung

Maschenregel $\sum_{j=1}^N U_j = 0$ Spannungen in Schleife

Schaltungen R-Reihe $R = \sum R_j$

R-Parallel $\frac{1}{R} = \sum \frac{1}{R_j}$

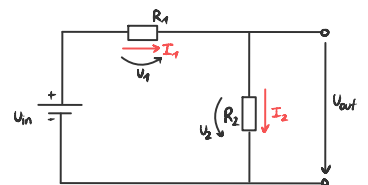
C-Reihe $\frac{1}{C} = \sum \frac{1}{C_j}$

C-Parallel $C = \sum C_j$

L-Reihe $L = \sum L_j$

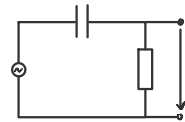
L-Parallel $\frac{1}{L} = \sum \frac{1}{L_j}$

Spezielle Schalt. Spannungsteiler $U_2 = U_{\text{out}} = U_{\text{in}} \cdot \frac{R_2}{R_1 + R_2}$



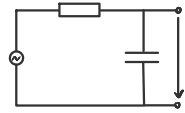
RC-Hochpass

$$U_{out} = U_{in} \cdot \sqrt{\frac{R^2}{(\frac{1}{\omega C})^2 + R^2}}$$



RC-Tiefpass

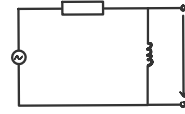
$$U_{out} = U_{in} \cdot \sqrt{\frac{1}{1 + (\omega RC)^2}}$$



$$f_G = \frac{\omega}{2\pi} = \frac{1}{2\pi RC}$$

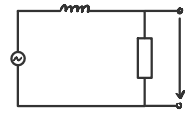
RL-Hochpass

$$U_{out} = U_{in} \cdot \sqrt{\frac{1}{1 + (\frac{R}{\omega L})^2}}$$



RL-Tiefpass

$$U_{out} = U_{in} \cdot \sqrt{\frac{R^2}{(\omega L)^2 + R^2}}$$



$$f_c = \frac{1}{2\pi} \cdot \frac{R}{L}$$

Trafo

$$\frac{U_1}{N_1} = \frac{U_2}{N_2}, \quad \frac{I_2}{I_1} = \frac{U_1}{U_2} = \frac{N_1}{N_2}$$

RC-Ein

$$I(t) = I_0 \cdot e^{-\frac{t}{\tau}}$$

$$U_C(t) = U_B(1 - e^{-\frac{t}{\tau}})$$

$$U_R(t) = U_B \cdot e^{-\frac{t}{\tau}}$$

$$\tau = R \cdot C$$

RC-Aus

$$I(t) = -\frac{U_C(0)}{R} \cdot e^{-\frac{t}{\tau}}$$

$$U_C(t) = U_C(0) \cdot e^{-\frac{t}{\tau}}$$

$$U_R(t) = -U_C(0) \cdot e^{-\frac{t}{\tau}}$$

$$U_B = R \cdot I_0$$

RL-Ein

$$I(t) = \frac{U_B}{R}(1 - e^{-\frac{t}{\tau}})$$

$$U_L(t) = U_B \cdot e^{-\frac{t}{\tau}}$$

$$U_R(t) = U_B(1 - e^{-\frac{t}{\tau}})$$

$$\tau = \frac{L}{R}$$

RL-Aus

$$I(t) = \frac{U_B}{R} \cdot e^{-\frac{t}{\tau}}$$

$$U_L(t) = -U_B \cdot e^{-\frac{t}{\tau}}$$

$$U_R(t) = U_B \cdot e^{-\frac{t}{\tau}}$$

Elektr. Schwingkreis

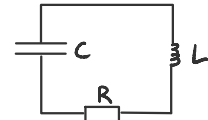
harmon. Schw.

$$\omega = \frac{1}{\sqrt{LC}}$$

$$I(t) = I_0 \cdot \sin(\omega t)$$

$$U_0 = L \cdot I_0 \cdot \omega$$

$$U_L(t) = U_0 \cdot \cos(\omega t)$$



Dämpfung

$$R_{krit} = R \cdot \sqrt{\frac{L}{C}}$$

RCL-Bandpass

$$\omega_0 = \sqrt{\frac{1}{LC} - \left(\frac{R}{2L}\right)^2}$$

$$\Delta\omega = \frac{R}{L}$$

Heiz'scher Dipol

$$\lambda = 2 \cdot l$$

$$f_A = \frac{c}{2L}$$

Optik

Elektromagnet. Wellen

$$\vec{E}(\vec{r}, t) = E_0 \cdot \sin(\vec{k} \cdot \vec{r} - \omega t)$$

$$E_0 = c \cdot B_0$$

$$\vec{B}(\vec{r}, t) = B_0 \cdot \sin(\vec{k} \cdot \vec{r} - \omega t)$$

Intensität

$$I = \frac{P}{A} = \frac{1}{2} \epsilon_0 c E_0^2 = \frac{1}{2 \mu_0 c} E_0^2$$

Impuls

Absorption

$$p = \frac{I}{c}$$

Reflexion

$$p = 2 \frac{I}{c}$$

in Materie $c_n = \frac{c}{n}$ $n = \sqrt{\epsilon_r}$

Absorption $P(x) = P_0 \cdot e^{-\mu \cdot x}$ $\mu = \text{Absorptionskoeff.}$

Strahlenoptik

Snellius $n_1 \cdot \sin(\alpha_1) = n_2 \cdot \sin(\alpha_2)$ $n_2 > n_1$: zum Lot

Totalreflexion $\alpha_T = \arcsin\left(\frac{n_2}{n_1}\right)$ $n_2 < n_1$

Abbildungen $D = \frac{1}{f}$ $\frac{1}{f} = (n-1) \cdot \left(\frac{1}{r_1} + \frac{1}{r_2}\right)$

2 Linsen $\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 \cdot f_2}$

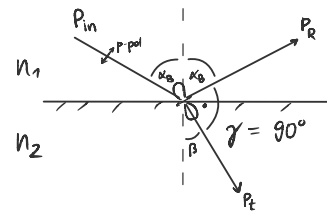
Abb.gesetze Abstände $\frac{1}{f} = \frac{1}{b} + \frac{1}{g}$ $b = \frac{g \cdot f}{g - f}$

Vergrößerung $V = \frac{B}{G} = \frac{|b|}{g} = \frac{f}{|g - f|}$

Polarisation von Licht

Malus $P_t = P_0 \cdot \cos(\alpha)^2$

Brewster-Reflexion $\alpha_B = \arctan\left(\frac{n_2}{n_1}\right)$



Optische Aktivität feste Stoffe $\alpha = \alpha_s \cdot l$

flüssige Stoffe $\alpha = \alpha_s \cdot c \cdot l$ $c = \text{Konzentration}$

Wellenoptik

Kohärenzzeit $\tau_c = \frac{1}{\Delta f}$

Kohärenzlänge $l_c = \tau_c \cdot c$

Mach-Zehnder-Interferometer $I_1 = I_0 \cdot \cos\left(\frac{k \cdot \Delta l}{2}\right)^2$

$I_2 = I_0 \cdot \sin\left(\frac{k \cdot \Delta l}{2}\right)^2$

Dünnschichtinterferenz Konstr. $2d \sqrt{n^2 - \sin(\alpha_m)^2} = (m - \frac{1}{2}) \cdot \lambda$

Destr. $2d \sqrt{n^2 - \sin(\alpha_m)^2} = m \cdot \lambda$

Bewegung Einzelspalt-Max $a \cdot \sin(\alpha) = (m + \frac{1}{2}) \cdot \lambda$

Einzelspalt-Min $a \cdot \sin(\alpha) = m \cdot \lambda$

Doppelspalt - Max $d \cdot \sin(\alpha) = m \cdot \lambda$ (und Gitter)

Doppelspalt - Min $d \cdot \sin(\alpha) = (m + \frac{1}{2}) \cdot \lambda$

Auflösung Rayleigh $\sin(\alpha_{\min}) = 1,22 \cdot \frac{\lambda}{D}$

Abbe $d_{\min} = \frac{\lambda}{n \cdot \sin(\alpha)}$

Quantenoptik

Energie $E_{\text{photon}} = h \cdot f = \hbar \cdot \omega$ $\omega = \frac{2\pi c}{\lambda}$

Impuls $p = \frac{h}{\lambda} = \hbar \cdot k$

Leistung $P = j \cdot \hbar \omega$ $j = \text{Photonenrate}$

Wien'sches Verschiebungsgesetz $\lambda_{\max} = \frac{2897,8 \mu\text{m} \cdot \text{K}}{T}$

Stefan-Boltzmann-Gesetz $P = \sigma \cdot A \cdot T^4$

Austrittsarbeit $W_A = h \cdot f_{\text{Grenz}}$

Compton-Streuung $\Delta\lambda = \lambda_c (1 - \cos(\phi))$, $\lambda_c = \frac{h}{m_e \cdot c}$

Quantenphysik

Eigenschaften von Quantenobjekten

Materie-Welle Wellenlänge $\lambda = \frac{h}{p} = \frac{h}{m \cdot v}$

Frequenz $f = \frac{E_{\text{kin}}}{h}$

Beschl. spannung $v = \sqrt{\frac{2q \cdot U}{m}}$

Heisenberg $\Delta x \cdot \Delta p \geq h$

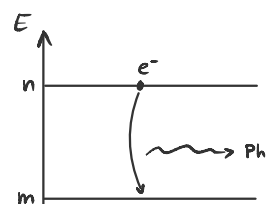
Atomphysik

Bohr Bahnradien $r_n = a_B \cdot \frac{n^2}{Z}$

Energien $E_n = -E_{Ry} \cdot \frac{Z^2}{n^2}$

Emission $\Delta E = h \cdot f = E_{Ry} \cdot Z^2 \left(\frac{1}{m^2} - \frac{1}{n^2} \right)$

$\lambda = \frac{h \cdot c}{\Delta E}$



Schrödinger	Quantenzahlen	$n = 1, 2, 3, \dots$	$\hat{=} \text{Schalen } (K, L, M, \dots)$
		$L = 0, 1, \dots, (n-1)$	$L = \hbar \sqrt{L(L+1)}$
		$m = 0, \pm 1, \pm 2, \dots, \pm L$	
	Spin	$m_s = \pm \frac{1}{2}$	

Kernphysik

Atomkern	Ladung	$q_{\text{kern}} = Z \cdot e^+ \quad (\approx (Z+N) \cdot u)$
	Masse	$m_{\text{kern}} = Z \cdot m_p + N \cdot m_n - \Delta m_K$
	Massendefekt	$\Delta m_K = \frac{E_{b,K}}{c^2} \quad E_{b,K} = \text{Bindungsenergie}$
Zerfall	β^-	${}_Z^A X_N \rightarrow {}_{Z+1}^A Y_{N-1}$
	β^+	${}_Z^A X_N \rightarrow {}_{Z-1}^A Y_{N+1}$
	Gesetz	$N(t) = N_0 \cdot e^{-t/\tau}$
		$T_{1/2} = \tau \cdot \ln(2)$
	Aktivität	$A = - \frac{dN}{dt} = \frac{N_0}{\tau} \cdot e^{-t/\tau}$