GLEICHUNGEN DER ELEKTRODYNAMIK

$$\frac{1}{\epsilon_0} \ \text{(SI)} \leftrightarrow 4\pi \ \text{(G)}$$

$$\vec{B} \ \text{(SI)} \leftrightarrow \frac{\vec{B}}{c} \ \text{(G)}$$

$$\epsilon_0\mu_0 \ \text{(SI)} \leftrightarrow \frac{1}{c^2} \ \text{(G)}$$

$$\vec{F}_1 = \frac{1}{4\pi\epsilon_0} q_1 q_2 \frac{\vec{r}_1 - \vec{r}_2}{|\vec{r}_1 - \vec{r}_2|^3} \qquad \text{Coulomb}$$

$$\vec{E}(\vec{r}) = \frac{1}{4\pi\epsilon_0} \int d^3r' \rho(\vec{r}\,') \frac{\vec{r} - \vec{r}\,'}{|\vec{r} - \vec{r}\,'|^3} \qquad elFeld$$

$$d\Omega = \frac{d\vec{a} \cdot \hat{r}}{r^2} \qquad \text{Raumwinkel}$$

$$\oint_S d\vec{a} \cdot \vec{E} = \frac{1}{\epsilon_0} \int_V d^3r \rho(\vec{r}) \qquad \text{Gaußsches Gesetz}$$

$$\operatorname{div} \vec{E}(\vec{r}) = \frac{\rho(\vec{r})}{\epsilon_0} \qquad \text{Gaußsches Gesetz}$$

$$\Phi(\vec{r}) = \frac{1}{4\pi\epsilon_0} \int d^3r' \frac{\rho(\vec{r}\,')}{|\vec{r} - \vec{r}\,'|} \qquad \text{el Potential}$$

$$\operatorname{div} \vec{E} = \frac{\rho}{\epsilon_0}, \qquad \operatorname{rot} \vec{E} = 0 \qquad \text{Elektrostatik}$$

$$\Phi(\vec{r}) = \frac{q}{4\pi\epsilon_0} \frac{\vec{d} \cdot (\vec{r} - \vec{r}\,')}{|\vec{r} - \vec{r}\,'|^3} \qquad \text{Dipolpotential}$$

$$\vec{p} = \int d^3r'\vec{r}'\rho(\vec{r}') \qquad \text{Dipolmoment}$$

$$\underline{Q} = \int d^3r'\rho(\vec{r}')(3\vec{r}' \otimes \vec{r}' - r'^2\underline{1}) \qquad \text{Quadrupolmoment}$$

$$\Phi(\vec{r}) = \frac{1}{4\pi\epsilon_0}\left[\frac{q}{r} + \frac{\vec{p}\cdot\vec{r}}{r^3} + \frac{\vec{r}\cdot\underline{Q}\cdot\vec{r}}{2r^5} + \dots\right] \qquad \text{Potential} - \text{Reihenentwicklung}$$

$$\underline{Q}(\vec{r}) = \int d^3r'(3\vec{r}' \otimes \vec{r}' - r'^2\underline{1})\rho(\vec{r}') \qquad \text{Quadrupoltensor}$$

$$\Delta\Phi = -\frac{\rho}{\epsilon_0}. \qquad \text{Poissonglg}$$

$$\int_V d^3r(\Phi\Delta\Psi - \Psi\Delta\Phi) = \oint_S da\left(\Phi\frac{\partial\Psi}{\partial n} - \Psi\frac{\partial\Phi}{\partial n}\right) \qquad \text{Greenscher Satz}$$

$$\Delta\frac{1}{|\vec{r} - \vec{r}'|} = -4\pi\delta(\vec{r} - \vec{r}') \qquad \text{Def Greensfkt}$$

$$G(\vec{r} - \vec{r}') = \frac{1}{|\vec{r} - \vec{r}'|} \qquad \text{Greensfkt}$$

$$e(\vec{r}) = \frac{\epsilon_0}{2}|\vec{E}(\vec{r})|^2 \qquad \text{el Energie}$$

$$F(k) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} dx\, f(x)e^{ikx} \qquad \text{Fouriertrafo}$$

$$f(x) = \frac{1}{\sqrt{2\pi}}\int_{-\infty}^{\infty} dk'\, F(k')e^{-ik'x} \qquad \text{Fourierrück}$$

$$\Phi(r,\theta) = \sum_{l=0}^{\infty}\left[A_l\, r^l + B_l\, r^{-(l+1)}\right]P_l(\cos\theta) \qquad \text{Legendreentwicklung}$$

$$\vec{D} = \epsilon_0 \vec{E} + \vec{P} \qquad \text{Polarisation}$$

$$\operatorname{div} \vec{D} = \rho \qquad \text{Diel Verschiebung}$$

$$\vec{j} = \rho \vec{v} \qquad \text{Stromdichte}$$

$$\nabla \cdot \vec{j} = 0 \qquad \text{Annahme Magnetostatik}$$

$$\vec{j} = \sigma \vec{E} \qquad \text{Ohm}$$

$$d\vec{B}(\vec{r}) = \frac{\mu_0}{4\pi}\, d^3r' \, \frac{\vec{j}(\vec{r}\,') \times (\vec{r} - \vec{r}\,')}{|\vec{r} - \vec{r}\,'|^3} \qquad \text{Biot} - \text{Savart}$$

$$d\vec{F}(\vec{r}) = d^3r \, \vec{j}(\vec{r}) \times \vec{B}(\vec{r}) \qquad \text{Ampere Kraftgesetz}$$

$$\vec{F} = -\frac{\mu_0}{4\pi} I I' \oint \oint (d\vec{l} \cdot d\vec{l}\,') \frac{\vec{r} - \vec{r}\,'}{|\vec{r} - \vec{r}\,'|^3} \qquad \text{Kraft zwischen curcuits}$$

$$\operatorname{div} \vec{B} = 0 \qquad \text{Quellfreiheit}$$

$$\nabla \times \vec{B}(\vec{r}) = \mu_0 \vec{j}(\vec{r}) \qquad \text{Ampere}$$

$$\oint_C d\vec{l} \cdot \vec{B} = \mu_0 \int_S d\vec{a} \cdot \vec{j} = \mu_0 I. \qquad \text{Ampere}$$

$$\vec{B} = \operatorname{rot} \vec{A} \qquad \text{Vektorpot}$$

$$\vec{A}(\vec{r}) = \frac{\mu_0}{4\pi} \int d^3r' \frac{\vec{j}(\vec{r}\,')}{|\vec{r} - \vec{r}\,'|} \qquad \text{Pot der Magn.statik}$$

$$\Delta \vec{A} = -\mu_0 \vec{j} \qquad \text{Poisson Magn.statik}$$

$$\vec{m} = \frac{1}{2} \int d^3r'\, \vec{r}\,' \times \vec{j}(\vec{r}\,') \qquad \text{Mag Dipolmoment}$$

$$\vec{B}(\vec{r}) = \frac{\mu_0}{4\pi} \left[\frac{3\hat{r}(\hat{r} \cdot \vec{m}) - \vec{m}}{r^3} \right] \qquad \text{Mag Dipolfeld}$$

$$\vec{H} = \frac{1}{\mu_0} \vec{B} - \vec{M} \qquad \text{Magnetisierung}$$

$$\nabla \times \vec{H} = \vec{j}, \qquad \nabla \cdot \vec{B} = 0 \qquad \text{Magnetostatik}$$

$$\Phi = \int_S d\vec{a} \cdot \vec{B} \qquad \text{mag Fluß}$$

$$\oint_C d\vec{l} \cdot \vec{E} = -\frac{d}{dt} \int_S d\vec{a} \cdot \vec{B} \qquad \text{Faraday}$$

$$\nabla \times \vec{E} + \frac{\partial \vec{B}}{\partial t} = 0 \qquad \text{Faraday}$$

$$dW = -UIdt = Id\Phi \qquad \text{Arbeit mag Fluß}$$

$$e = \frac{B^2}{2\mu} \qquad \text{mag Energie}$$

$$\Phi_i = \sum_{j=1}^{n} L_{ij} I_j \qquad \text{Induktivität}$$

$$W = \frac{1}{2} \sum_i \sum_j L_{ij} I_i I_j \qquad \text{Arbeit und Indukt}$$

$$L_{ij} = \frac{\mu_0}{4\pi} \oint \oint \frac{d\vec{r}_i \cdot d\vec{r}_j}{|\vec{r}_i - \vec{r}_j|} \qquad \text{Induktivität}$$

$$\begin{aligned} \operatorname{div} \vec{D} &= \rho \\ \operatorname{rot} \vec{E} &= 0 \\ \operatorname{rot} \vec{H} &= \vec{j} \\ \operatorname{div} \vec{B} &= 0 \qquad \text{Magneto} - \text{Elektrostatik} \end{aligned}$$

$$\begin{aligned} \operatorname{div} \vec{D} &= \rho \\ \operatorname{rot} \vec{E} + \frac{\partial \vec{B}}{\partial t} &= 0 \\ \operatorname{rot} \vec{H} &= \vec{j} \\ \operatorname{div} \vec{B} &= 0 \qquad \text{Mit Induktion} \end{aligned}$$

$$0 = \operatorname{div} \operatorname{rot} \vec{H} = \operatorname{div} \vec{j} = -\frac{\partial \rho}{\partial t} \neq 0. \qquad \text{Fehler Ampere} - \text{Continuity}$$

$$\begin{aligned} \frac{\partial}{\partial t} (\operatorname{div} \vec{D}) + \operatorname{div} \vec{j} &= 0 \\ \operatorname{div} \left(\vec{j} + \frac{\partial \vec{D}}{\partial t} \right) &= 0 \qquad \text{Verschiebestrom} \end{aligned}$$

$$\begin{aligned} \operatorname{div} \vec{D} &= \rho \\ \operatorname{div} \vec{B} &= 0 \\ \operatorname{rot} \vec{E} &= -\frac{\partial \vec{B}}{\partial t} \\ \operatorname{rot} \vec{H} &= \vec{j} + \frac{\partial \vec{D}}{\partial t} \qquad \text{Maxwellglgen} \end{aligned}$$

$$\oint_S d\vec{a} \cdot \vec{D} = \int_V dV\,\rho$$
$$\oint_S d\vec{a} \cdot \vec{B} = 0$$
$$\oint_C d\vec{l} \cdot \vec{E} = -\frac{d}{dt}\int_S d\vec{a} \cdot \vec{B}$$
$$\oint_C d\vec{l} \cdot \vec{H} = \int_S d\vec{a} \cdot (\vec{j} + \dot{\vec{D}}) \qquad \text{Maxwellglgen}$$

$$\vec{E} = -\nabla\Phi - \frac{\partial \vec{A}}{\partial t} \qquad \text{elmag Potential}$$

$$\nabla \cdot \vec{A}' + \frac{1}{c^2}\frac{\partial \Phi'}{\partial t} = 0 \qquad \text{Lorenzeichung}$$

$$\Box\Phi = -\rho/\epsilon_0,$$
$$\Box\vec{A} = -\mu_0\vec{j} \qquad \text{Maxwellglgen Lorenzeichung}$$

$$\vec{S} = \frac{1}{\mu_0}\vec{E} \times \vec{B} \qquad \text{Poyntingvektor}$$

$$\vec{p} = \vec{S}/c^2 \qquad \text{Impulsdichte Feld}$$

$$\underline{T} = \epsilon_0\left[\vec{E} \otimes \vec{E} + c^2\vec{B} \otimes \vec{B} - \frac{1}{2}(E^2 + c^2B^2)\,\underline{1}\right] \qquad \text{Energieglg Feld}$$

$$\Delta\vec{E} - \frac{1}{c^2}\frac{\partial^2\vec{E}}{\partial t^2} = 0 \qquad \text{hom Wellenglg}$$

$$\vec{E} = \vec{E}_0 e^{i(\pm\vec{k}\cdot\vec{r} - \omega t)} \qquad \text{ebene Welle}$$

$$\vec{F}(\theta, \phi)\frac{e^{\pm ikr}}{r} \qquad \text{Kugelwelle}$$

$$\vec{k} \cdot \vec{E}_0 = 0, \qquad \vec{k} \cdot \vec{B}_0 = 0 \qquad \text{Ortho Welle}$$

$$c\vec{B}_0 = \pm \hat{k} \times \vec{E}_0 \qquad \text{Ortho Welle}$$

$$G_+(\vec{r}, t; \vec{r}\,', t') = \frac{\delta\left(t - t' - \frac{|\vec{r}-\vec{r}\,'|}{c}\right)}{|\vec{r} - \vec{r}\,'|} \qquad \text{retardierte Greensfkt}$$

$$\Phi(\vec{r}, t) = \frac{1}{4\pi\epsilon_0} \int d^3r' \frac{\rho(\vec{r}\,', t - |\vec{r} - \vec{r}\,'|/c)}{|\vec{r} - \vec{r}\,'|} \qquad \text{retardiertes Potential}$$

$$\vec{A}(\vec{r}, t) = \frac{\mu_0}{4\pi} \int d^3r' \frac{\vec{j}(\vec{r}\,', t - |\vec{r} - \vec{r}\,'|/c)}{|\vec{r} - \vec{r}\,'|} \qquad \text{retardiertes Vektorpot}$$

$$\Phi(\vec{r}, t) = \frac{e}{4\pi\epsilon_0} \int d^3r' \, \frac{\delta(\vec{r}\,' - \vec{r}_0(t - |\vec{r} - \vec{r}\,'|/c))}{|\vec{r} - \vec{r}\,'|} \qquad \text{retardierte Pktldg}$$

$$\vec{s} = \vec{r}\,' - \vec{r}_0(t - |\vec{r} - \vec{r}\,'|/c) \qquad \text{retardierte Int.variable}$$

$$x' = \frac{x - ct\,(v/c)}{\sqrt{1 - v^2/c^2}} \qquad \text{Lorenztrafo}$$

$$ct' = \frac{ct - x\,(v/c)}{\sqrt{1 - v^2/c^2}} \qquad \text{Lorenztrafo}$$

$$l = l_0\sqrt{1 - \frac{v^2}{c^2}} \qquad \text{Längenkontraktion}$$

$$t = \frac{\tau}{\sqrt{1 - v^2/c^2}} \qquad \text{Zeitdilation}$$

$$d\tau = dt\sqrt{1 - v^2/c^2} \qquad \text{Eigenzeit}$$

$$x_\mu = \eta_{\mu\nu} x^\nu = (ct, -x, -y, -z) \qquad 4-\text{Ort}$$

$$u^\mu = \frac{1}{\sqrt{1 - \vec{u}\cdot\vec{u}/c^2}} \begin{pmatrix} c \\ \vec{u} \end{pmatrix} \qquad 4-\text{Geschw}$$

$$A^\mu = \begin{pmatrix} \Phi/c \\ \vec{A} \end{pmatrix} \qquad 4-\text{Potential}$$

$$j^\mu = \begin{pmatrix} c\rho \\ \vec{j} \end{pmatrix} \qquad 4-\text{Strom}$$

$$\frac{\partial \rho}{\partial t} + \nabla \cdot \vec{j} = 0 \qquad \to \partial_\mu j^\mu = 0 \qquad \text{Kontinuitätsglg}$$

$$\partial_\mu A^\mu = \frac{\partial A^0}{c\partial t} + \nabla \cdot \vec{A} = 0 \qquad \text{Lorenzeichung}$$

$$A'_\mu = \frac{\partial x^\alpha}{\partial x'^\mu} A_\alpha. \qquad \text{Vektortrafo}$$

$$T'^{\mu\nu} = \frac{\partial x'^\mu}{\partial x^\alpha} \frac{\partial x'^\nu}{\partial x^\beta} T^{\alpha\beta} \qquad \text{kontra Tensortrafo}$$

$$T'_{\mu\nu} = \frac{\partial x^\alpha}{\partial x'^\mu} \frac{\partial x^\beta}{\partial x'^\nu} T_{\alpha\beta} \qquad \text{kov Tensortrafo}$$

$$\partial_\mu = \nabla_\mu = \partial_\mu = \frac{\partial}{\partial x^\mu} = \left(\frac{\partial}{c\partial t}, \nabla \right) \qquad 4-\text{Gradient}$$

$$\partial^\mu = \frac{\partial}{\partial x_\mu} = \eta^{\mu\nu} \partial_\nu = \begin{pmatrix} \frac{\partial}{c\partial t} \\ -\nabla \end{pmatrix}$$

$$\Box \equiv \partial_\mu \partial^\mu = \frac{\partial^2}{c^2 \partial t^2} - \Delta \qquad \text{Wellenoperator}$$

$$F^{\mu\nu} = \partial^\mu A^\nu - \partial^\nu A^\mu \qquad \text{Feldstärketensor}$$

$$\begin{aligned} E_x/c &= F^{10} \\ E_y/c &= F^{20} \\ E_z/c &= F^{30} \\ B_x &= F^{32} \\ B_y &= F^{13} \\ B_z &= F^{21} \qquad \text{Feldstärketensor} \end{aligned}$$

$$\partial_\mu F^{\mu\nu} = \mu_0 j^\nu \qquad \text{kov inhom Maxwellglg}$$

$$\partial^\kappa F^{\mu\nu} + \partial^\mu F^{\nu\kappa} + \partial^\nu F^{\kappa\mu} = 0 \qquad \text{kov hom Maxwellglg}$$

$$*F^{\alpha\beta} = \frac{1}{2}\epsilon^{\alpha\beta\gamma\delta} F_{\gamma\delta} \qquad \text{dualer Feldstärketensor}$$

$$\partial_\mu *F^{\mu\nu} = 0 \qquad \text{kov hom Maxwellglg}$$

$$\delta \int d^4x \mathcal{L} = 0 \qquad 4 - \text{Wirkung}$$

$$\partial_\mu \frac{\partial \mathcal{L}}{\partial(\partial_\mu A_\nu)} - \frac{\partial \mathcal{L}}{\partial A_\nu} = 0 \qquad \text{Lag II } 4 - \text{Pot}$$

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} \qquad \text{kov Lagfkt EDyn Vakuum}$$

$$\mathcal{L} = -\frac{1}{4} F_{\mu\nu} F^{\mu\nu} - \mu_0 A_\mu j^\mu \qquad \text{kov Lagfkt EDyn}$$

$$\mathcal{L} = \frac{\epsilon_0}{2} E^2 - \frac{1}{2\mu_0} B^2 - \rho\Phi + \vec{j} \cdot \vec{A} \qquad \text{klass Lagfkt EDyn}$$

$$\frac{\partial}{\partial t}\frac{\partial \mathcal{L}}{\partial \dot{\Phi}} + \sum_{i=1}^{3}\frac{\partial}{\partial x_i}\frac{\partial \mathcal{L}}{\partial(\partial_i \Phi)} - \frac{\partial \mathcal{L}}{\partial \Phi} = 0 \qquad \text{klass Lag II EDyn}$$

$$\frac{\partial}{\partial t}\frac{\partial \mathcal{L}}{\partial \dot{A}_j} + \sum_{i=1}^{3}\frac{\partial}{\partial x_i}\frac{\partial \mathcal{L}}{\partial(\partial_i A_j)} - \frac{\partial \mathcal{L}}{\partial A_j} = 0 \qquad \text{klass Lag II EDyn}$$

$$\mathcal{H} = \frac{\partial \mathcal{L}}{\partial(\partial_\alpha A_\beta)}\partial_\alpha A_\beta - \mathcal{L} \qquad \text{kov Hamfkt der EDyn}$$

$$T^{\mu\nu} = \frac{\partial \mathcal{L}}{\partial(\partial_\mu A_\beta)}\partial^\nu A_\beta - \eta^{\mu\nu}\mathcal{L} \qquad \text{Energie} - \text{Impuls} - \text{Tensor}$$