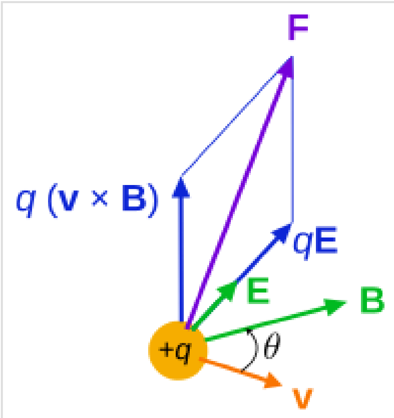
List of electromagnetism equations

This article summarizes equations in the theory of electromagnetism.

Definitions

Here subscripts e and m are used to differ between electric and magnetic charges. The definitions for monopoles are of theoretical interest, although real magnetic dipoles can be described using pole strengths. There are two possible units for monopole strength, Wb (Weber) and A m (Ampere metre). Dimensional analysis shows that magnetic charges relate by $q_m(\mathrm{Wb}) = \mu_0\, q_m(\mathrm{Am})$.



Lorentz force on a charged particle (of charge q) in motion (velocity **v**), used as the definition of the **E** field and **B** field.

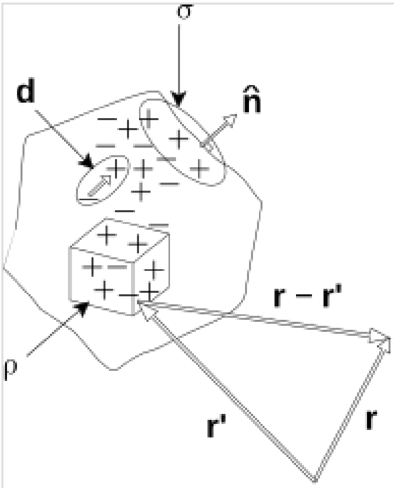
Initial quantities

Quantity (common name/s)	(Common) symbol/s	SI units	Dimension
Electric charge	q_e, q, Q	C = As	[I][T]
Monopole strength, magnetic charge	q_m, g, p	Wb or Am	$[L]^2[M][T]^{-2}\,[I]^{-1}$ (Wb) [I][L] (Am)

Electric quantities

Contrary to the strong analogy between (classical) gravitation and electrostatics, there are no "centre of charge" or "centre of electrostatic attraction" analogues.

Electric transport



Continuous charge distribution. The volume charge density ρ is the amount of charge per unit volume (cube), surface charge density σ is amount per unit surface area (circle) with outward unit normal **n̂**, **d** is the dipole moment between two point charges, the volume density of these is the polarization density **P**. Position vector **r** is a point to calculate the electric field; **r′** is a point in the charged object.

Quantity (common name/s)	(Common) symbol/s	Defining equation	SI units	Dimension
Linear, surface, volumetric charge density	λ_e for Linear, σ_e for surface, ρ_e for volume.	$q_e = \int \lambda_e \mathrm{d}\ell$ $q_e = \iint \sigma_e \mathrm{d}S$ $q_e = \iiint \rho_e \mathrm{d}V$	C m^{-n}, n = 1, 2, 3	$[I][T][L]^{-n}$
Capacitance	C	$C = \frac{\mathrm{d}q}{\mathrm{d}V}$ V = voltage, *not* volume.	F = C V^{-1}	$[I]^2[T]^4[L]^{-2}[M]^{-1}$
Electric current	I	$I = \frac{\mathrm{d}q}{\mathrm{d}t}$	A	[I]
Electric current density	**J**	$I = \mathbf{J} \cdot \mathrm{d}\mathbf{S}$	A m^{-2}	$[I][L]^{-2}$
Displacement current density	$\mathbf{J}_\mathrm{d}$	$\mathbf{J}_\mathrm{d} = \frac{\partial \mathbf{D}}{\partial t} = \varepsilon_0 \left(\frac{\partial \mathbf{E}}{\partial t}\right)$	A m^{-2}	$[I][L]^{-2}$
Convection current density	$\mathbf{J}_\mathrm{c}$	$\mathbf{J}_\mathrm{c} = \rho \mathbf{v}$	A m^{-2}	$[I][L]^{-2}$

Electric fields

Quantity (common name/s)	(Common) symbol/s	Defining equation	SI units	Dimension
Electric field, field strength, flux density, potential gradient	**E**	$\mathbf{E} = \frac{\mathbf{F}}{q}$	N C^{-1} = V m^{-1}	[M][L][T]$^{-3}$[I]$^{-1}$
Electric flux	Φ_E	$\Phi_E = \int_S \mathbf{E} \cdot \mathrm{d}\mathbf{A}$	N m^2 C^{-1}	[M][L]^3[T]$^{-3}$[I]$^{-1}$
Absolute permittivity;	ε	$\varepsilon = \varepsilon_r \varepsilon_0$	F m^{-1}	[I]^2 [T]^4 [M]$^{-1}$ [L]$^{-3}$
Electric dipole moment	**p**	$\mathbf{p} = q\mathbf{a}$ **a** = charge separation directed from -ve to +ve charge	C m	[I][T][L]
Electric Polarization, polarization density	**P**	$\mathbf{P} = \frac{\mathrm{d}\langle\mathbf{p}\rangle}{\mathrm{d}V}$	C m^{-2}	[I][T][L]$^{-2}$
Electric displacement field, flux density	**D**	$\mathbf{D} = \varepsilon\mathbf{E} = \varepsilon_0\mathbf{E} + \mathbf{P}$	C m^{-2}	[I][T][L]$^{-2}$
Electric displacement flux	Φ_D	$\Phi_D = \int_S \mathbf{D} \cdot \mathrm{d}\mathbf{A}$	C	[I][T]
Absolute electric potential, EM scalar potential relative to point r_0 **Theoretical:** $r_0 = \infty$ **Practical:** $r_0 = R_{\text{earth}}$ **(Earth's radius)**	φ , V	$V = -\frac{W_{\infty r}}{q} = -\frac{1}{q}\int_{\infty}^{r} \mathbf{F} \cdot \mathrm{d}\mathbf{r} = -\int_{r_1}^{r_2} \mathbf{E} \cdot \mathrm{d}\mathbf{r}$	V = J C^{-1}	[M] [L]^2 [T]$^{-3}$ [I]$^{-1}$
Voltage, Electric potential difference	$\Delta\varphi$,ΔV	$\Delta V = -\frac{\Delta W}{q} = -\frac{1}{q}\int_{r_1}^{r_2} \mathbf{F} \cdot \mathrm{d}\mathbf{r} = -\int_{r_1}^{r_2} \mathbf{E} \cdot \mathrm{d}\mathbf{r}$	V = J C^{-1}	[M] [L]^2 [T]$^{-3}$ [I]$^{-1}$

Magnetic quantities

Magnetic transport

Quantity (common name/s)	(Common) symbol/s	Defining equation	SI units	Dimension
Linear, surface, volumetric pole density	λ_m for Linear, σ_m for surface, ρ_m for volume.	$q_m = \int \lambda_m \mathrm{d}\ell$ $q_m = \iint \sigma_m \mathrm{d}S$ $q_m = \iiint \rho_m \mathrm{d}V$	Wb m^{-n} A m$^{(-n+1)}$, n = 1, 2, 3	[L]^2[M][T]$^{-2}$ [I]$^{-1}$ (Wb) [I][L] (Am)
Monopole current	I_m	$I_m = \frac{\mathrm{d}q_m}{\mathrm{d}t}$	Wb s^{-1} A m s^{-1}	[L]^2[M][T]$^{-3}$ [I]$^{-1}$ (Wb) [I][L][T]$^{-1}$ (Am)
Monopole current density	$\mathbf{J}_\mathrm{m}$	$I = \iint \mathbf{J}_\mathrm{m} \cdot \mathrm{d}\mathbf{A}$	Wb s^{-1} m^{-2} A m^{-1} s^{-1}	[M][T]$^{-3}$ [I]$^{-1}$ (Wb) [I][L]$^{-1}$[T]$^{-1}$ (Am)

Magnetic fields

Quantity (common name/s)	(Common) symbol/s	Defining equation	SI units	Dimension
Magnetic field, field strength, flux density, induction field	**B**	$\mathbf{F} = q_e \left(\mathbf{v} \times \mathbf{B} \right)$	T = N A^{-1} m^{-1} = Wb m^{-2}	[M][T]$^{-2}$[I]$^{-1}$
Magnetic potential, EM vector potential	**A**	$\mathbf{B} = \nabla \times \mathbf{A}$	T m = N A^{-1} = Wb m^{3}	[M][L][T]$^{-2}$[I]$^{-1}$
Magnetic flux	Φ_B	$\Phi_B = \int_S \mathbf{B} \cdot \mathrm{d}\mathbf{A}$	Wb = T m^2	[L]^2[M][T]$^{-2}$[I]$^{-1}$
Magnetic permeability	μ	$\mu = \mu_r \, \mu_0$	V·s·A^{-1}·m^{-1} = N·A^{-2} = T·m·A^{-1} = Wb·A^{-1}·m^{-1}	[M][L][T]$^{-2}$[I]$^{-2}$
Magnetic moment, magnetic dipole moment	**m**, **μB**, **Π**	Two definitions are possible: using pole strengths, $\mathbf{m} = q_m \mathbf{a}$ using currents: $\mathbf{m} = NIA\hat{\mathbf{n}}$ **a** = pole separation *N* is the number of turns of conductor	A m^2	[I][L]^2
Magnetization	**M**	$\mathbf{M} = \frac{\mathrm{d} \langle \mathbf{m} \rangle}{\mathrm{d}V}$	A m^{-1}	[I] [L]$^{-1}$
Magnetic field intensity, (AKA field strength)	**H**	Two definitions are possible: most common: $\mathbf{B} = \mu \mathbf{H} = \mu_0 \left(\mathbf{H} + \mathbf{M} \right)$ using pole strengths,[1] $\mathbf{H} = \frac{\mathbf{F}}{q_m}$	A m^{-1}	[I] [L]$^{-1}$
Intensity of magnetization, magnetic polarization	**I**, **J**	$\mathbf{I} = \mu_0 \mathbf{M}$	T = N A^{-1} m^{-1} = Wb m^{-2}	[M][T]$^{-2}$[I]$^{-1}$
Self Inductance	*L*	Two equivalent definitions are possible: $L = N \left(\frac{\mathrm{d}\Phi}{\mathrm{d}I} \right)$ $L \left(\frac{\mathrm{d}I}{\mathrm{d}t} \right) = -NV$	H = Wb A^{-1}	[L]^2 [M] [T]$^{-2}$ [I]$^{-2}$

Mutual inductance	*M*	Again two equivalent definitions are possible: $$M_1 = N\left(\frac{\mathrm{d}\Phi_2}{\mathrm{d}I_1}\right)$$ $$M\left(\frac{\mathrm{d}I_2}{\mathrm{d}t}\right) = -NV_1$$ 1,2 subscripts refer to two conductors/inductors mutually inducing voltage/ linking magnetic flux through each other. They can be interchanged for the required conductor/inductor; $$M_2 = N\left(\frac{\mathrm{d}\Phi_1}{\mathrm{d}I_2}\right)$$ $$M\left(\frac{\mathrm{d}I_1}{\mathrm{d}t}\right) = -NV_2$$	H = Wb A^{-1}	[L]^2 [M] [T]$^{-2}$ [I]$^{-2}$
Gyromagnetic ratio (for charged particles in a magnetic field)	*γ*	$\omega = \gamma B$	Hz T^{-1}	[M]$^{-1}$[T][I]

Electric circuits

DC circuits, general definitions

Quantity (common name/s)	(Common) symbol/s	Defining equation	SI units	Dimension
Terminal Voltage for Power Supply	V_{ter}		V = J C^{-1}	[M] [L]^2 [T]$^{-3}$ [I]$^{-1}$
Load Voltage for Circuit	V_{load}		V = J C^{-1}	[M] [L]^2 [T]$^{-3}$ [I]$^{-1}$
Internal resistance of power supply	R_{int}	$R_{\text{int}} = \frac{V_{\text{ter}}}{I}$	Ω = V A^{-1} = J s C^{-2}	[M][L]^2 [T]$^{-3}$ [I]$^{-2}$
Load resistance of circuit	R_{ext}	$R_{\text{ext}} = \frac{V_{\text{load}}}{I}$	Ω = V A^{-1} = J s C^{-2}	[M][L]^2 [T]$^{-3}$ [I]$^{-2}$
Electromotive force (emf), voltage across entire circuit including power supply, external components and conductors	*E*	$\mathcal{E} = V_{\text{ter}} + V_{\text{load}}$	V = J C^{-1}	[M] [L]^2 [T]$^{-3}$ [I]$^{-1}$

AC circuits

Quantity (common name/s)	(Common) symbol/s	Defining equation	SI units	Dimension
Resistive load voltage	V_R	$V_R = I_R R$	V = J C^{-1}	[M] [L]^2 [T]$^{-3}$ [I]$^{-1}$
Capacitive load voltage	V_C	$V_C = I_C X_C$	V = J C^{-1}	[M] [L]^2 [T]$^{-3}$ [I]$^{-1}$
Inductive load voltage	V_L	$V_L = I_L X_L$	V = J C^{-1}	[M] [L]^2 [T]$^{-3}$ [I]$^{-1}$
Capacitive reactance	X_C	$X_C = \frac{1}{\omega_\mathrm{d} C}$	Ω^{-1} m^{-1}	[I]^2 [T]^3 [M]$^{-2}$ [L]$^{-2}$
Inductive reactance	X_L	$X_L = \omega_d L$	Ω^{-1} m^{-1}	[I]^2 [T]^3 [M]$^{-2}$ [L]$^{-2}$
AC electrical impedance	Z	$V = IZ$ $Z = \sqrt{R^2 + (X_L - X_C)^2}$	Ω^{-1} m^{-1}	[I]^2 [T]^3 [M]$^{-2}$ [L]$^{-2}$
Phase constant	δ, φ	$\tan\phi = \frac{X_L - X_C}{R}$	dimensionless	dimensionless
AC peak current	I_0	$I_0 = I_\mathrm{rms}\sqrt{2}$	A	[I]
AC root mean square current	I_rms	$I_\mathrm{rms} = \sqrt{\frac{1}{T}\int_0^T [I(t)]^2 \mathrm{d}t}$	A	[I]
AC peak voltage	V_0	$V_0 = V_\mathrm{rms}\sqrt{2}$	V = J C^{-1}	[M] [L]^2 [T]$^{-3}$ [I]$^{-1}$
AC root mean square voltage	V_rms	$V_\mathrm{rms} = \sqrt{\frac{1}{T}\int_0^T [V(t)]^2 \mathrm{d}t}$	V = J C^{-1}	[M] [L]^2 [T]$^{-3}$ [I]$^{-1}$
AC emf, root mean square	$\mathcal{E}_\mathrm{rms}, \sqrt{\langle\mathcal{E}\rangle}$	$\mathcal{E}_\mathrm{rms} = \mathcal{E}_\mathrm{m}/\sqrt{2}$	V = J C^{-1}	[M] [L]^2 [T]$^{-3}$ [I]$^{-1}$
AC average power	$\langle P\rangle$	$\langle P\rangle = \mathcal{E} I_\mathrm{rms}\cos\phi$	W = J s^{-1}	[M] [L]^2 [T]$^{-3}$
Capacitive time constant	τ_C	$\tau_C = RC$	s	[T]
Inductive time constant	τ_L	$\tau_L = \frac{L}{R}$	s	[T]

Magnetic circuits

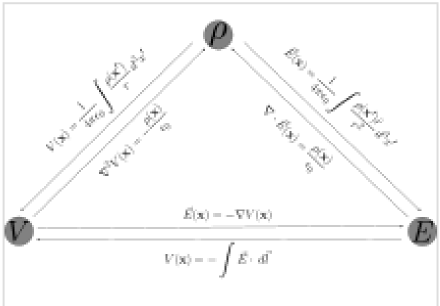
Quantity (common name/s)	(Common) symbol/s	Defining equation	SI units	Dimension
Magnetomotive force, mmf	F, $\mathcal{F}, \mathcal{M}$	$\mathcal{M} = NI$ N = number of turns of conductor	A	[I]

Electromagnetism

Electric fields

General Classical Equations

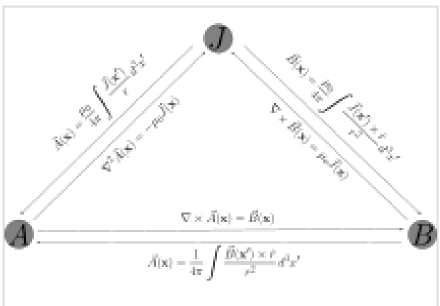
Physical situation	Equations
Electric potential gradient and field	$\mathbf{E} = -\nabla V$ $\Delta V = -\int_{r_1}^{r_2} \mathbf{E} \cdot d\mathbf{r}$
Point charge	$\mathbf{E}(\mathbf{r}) = \frac{q}{4\pi\varepsilon_0}\frac{\hat{\mathbf{r}}}{\lvert\mathbf{r}\rvert^2} = \frac{q}{4\pi\varepsilon_0}\frac{\mathbf{r}}{\lvert\mathbf{r}\rvert^3}$
At a point in a local array of point charges	$\mathbf{E}(\mathbf{r}) = \frac{1}{4\pi\varepsilon_0}\sum_{i=1}^{n} q_i \frac{\hat{\mathbf{r}}_i}{\lvert\mathbf{r_i} - \mathbf{r}\rvert^2} = \frac{1}{4\pi\varepsilon_0}\sum_{i=1}^{n} q_i \frac{\mathbf{r}_i}{\lvert\mathbf{r_i} - \mathbf{r}\rvert^3}$
At a point due to a continuum of charge	$\mathbf{E}(\mathbf{r}) = \frac{1}{4\pi\varepsilon_0}\iiint \rho(\mathbf{r}')\frac{\mathbf{r}'}{\lvert\mathbf{r}'\rvert^3}\mathrm{d}^3\lvert\mathbf{r}'\rvert$
Electrostatic torque and potential energy due to non-uniform fields and dipole moments	$\boldsymbol{\tau} = \int_V \mathrm{d}\mathbf{p} \times \mathbf{E}$ $U = -\int_V \mathrm{d}\mathbf{p} \cdot \mathbf{E}$



Summary of electrostatic relations between electric potential, electric field and charge density. Here, $\mathbf{r} = \mathbf{x} - \mathbf{x}'$.

Magnetic fields and moments

General classical equations



Summary of magnetostatic relations between magnetic vector potential, magnetic field and current density. Here, $\mathbf{r} = \mathbf{x} - \mathbf{x}'$.

Physical situation	Equations
Magnetic potential, EM vector potential	$\mathbf{B} = \nabla \times \mathbf{A}$
Due to a magnetic moment	$\mathbf{A} = \frac{\mu_0}{4\pi} \frac{\mathbf{m} \times \mathbf{r}}{\lvert\mathbf{r}\rvert^3}$ $\mathbf{B}(\mathbf{r}) = \nabla \times \mathbf{A} = \frac{\mu_0}{4\pi} \left(\frac{3\mathbf{r}(\mathbf{m} \cdot \mathbf{r})}{\lvert\mathbf{r}\rvert^5} - \frac{\mathbf{m}}{\lvert\mathbf{r}\rvert^3} \right)$
Magnetic moment due to a current distribution	$\mathbf{m} = \frac{1}{2} \int_V \mathbf{r} \times \mathbf{J} \mathrm{d}V$
Magnetostatic torque and potential energy due to non-uniform fields and dipole moments	$\boldsymbol{\tau} = \int_V \mathrm{d}\mathbf{m} \times \mathbf{B}$ $U = -\int_V \mathrm{d}\mathbf{m} \cdot \mathbf{B}$

Electric circuits and electronics

Below N = number of conductors or circuit components. Subscript *net* refers to the equivalent and resultant property value.

Physical situation	Nomenclature	Series	Parallel
Resistors and conductors	R_i = resistance of resistor or conductor i G_i = conductance of resistor or conductor i	$R_{\text{net}} = \sum_{i=1}^{N} R_i$ $\frac{1}{G_{\text{net}}} = \sum_{i=1}^{N} \frac{1}{G_i}$	$\frac{1}{R_{\text{net}}} = \sum_{i=1}^{N} \frac{1}{R_i}$ $G_{\text{net}} = \sum_{i=1}^{N} G_i$
Charge, capacitors, currents	C_i = capacitance of capacitor i q_i = charge of charge carrier i	$q_{\text{net}} = \sum_{i=1}^{N} q_i$ $\frac{1}{C_{\text{net}}} = \sum_{i=1}^{N} \frac{1}{C_i}$ $I_{\text{net}} = I_i$	$q_{\text{net}} = \sum_{i=1}^{N} q_i$ $C_{\text{net}} = \sum_{i=1}^{N} C_i$ $I_{\text{net}} = \sum_{i=1}^{N} I_i$
Inductors	L_i = self-inductance of inductor i L_{ij} = self-inductance element ij of L matrix M_{ij} = mutual inductance between inductors i and j	$L_{\text{net}} = \sum_{i=1}^{N} L_i$	$\frac{1}{L_{\text{net}}} = \sum_{i=1}^{N} \frac{1}{L_i}$ $V_i = \sum_{j=1}^{N} L_{ij} \frac{\mathrm{d}I_j}{\mathrm{d}t}$

Series circuit equations

Circuit	DC Circuit equations	AC Circuit equations
RC circuits	Circuit equation $R\frac{\mathrm{d}q}{\mathrm{d}t}+\frac{q}{C}=\mathcal{E}$ Capacitor charge $q=C\mathcal{E}\left(1-e^{-t/RC}\right)$ Capacitor discharge $q=C\mathcal{E}e^{-t/RC}$	
RL circuits	Circuit equation $L\frac{\mathrm{d}I}{\mathrm{d}t}+RI=\mathcal{E}$ Inductor current rise $I=\frac{\mathcal{E}}{R}\left(1-e^{-Rt/L}\right)$ Inductor current fall $I=\frac{\mathcal{E}}{R}e^{-t/\tau_L}=I_0e^{-Rt/L}$	
LC circuits	Circuit equation $L\frac{\mathrm{d}^2q}{\mathrm{d}t^2}+\frac{q}{C}=\mathcal{E}$	Circuit equation $L\frac{\mathrm{d}^2q}{\mathrm{d}t^2}+\frac{q}{C}=\mathcal{E}\sin(\omega_0t+\phi)$ Circuit resonant frequency $\omega_{\mathrm{res}}=\frac{1}{\sqrt{LC}}$ Circuit charge $q=q_0\cos(\omega t+\phi)$ Circuit current $I=-\omega q_0\sin(\omega t+\phi)$ Circuit electrical potential energy $U_E=\frac{q^2}{2C}=\frac{q_0^2\cos^2(\omega t+\phi)}{2C}$ Circuit magnetic potential energy $U_B=\frac{q_0^2\sin^2(\omega t+\phi)}{2C}$

RLC circuits	Circuit equation $L\frac{\mathrm{d}^2q}{\mathrm{d}t^2}+R\frac{\mathrm{d}q}{\mathrm{d}t}+\frac{q}{C}=\mathcal{E}$	Circuit equation $L\frac{\mathrm{d}^2q}{\mathrm{d}t^2}+R\frac{\mathrm{d}q}{\mathrm{d}t}+\frac{q}{C}=\mathcal{E}\sin(\omega_0 t+\phi)$ Circuit charge $q=q_0 eT^{-Rt/2L}\cos(\omega' t+\phi)$

See also

- Defining equation (physical chemistry)
- Fresnel equations
- List of equations in classical mechanics
- List of equations in fluid mechanics
- List of equations in gravitation
- List of equations in nuclear and particle physics
- List of equations in quantum mechanics
- List of equations in wave theory
- List of photonics equations
- List of relativistic equations
- SI electromagnetism units
- Table of thermodynamic equations

Footnotes

1. M. Mansfield; C. O'Sullivan (2011). *Understanding Physics* (2nd ed.). John Wiley & Sons. ISBN 978-0-470-74637-0.

Sources

- P.M. Whelan; M.J. Hodgeson (1978). *Essential Principles of Physics* (2nd ed.). John Murray. ISBN 0-7195-3382-1.
- G. Woan (2010). *The Cambridge Handbook of Physics Formulas* (https://archive.org/details/cambridgehandboo0000woan). Cambridge University Press. ISBN 978-0-521-57507-2.
- A. Halpern (1988). *3000 Solved Problems in Physics, Schaum Series*. Mc Graw Hill. ISBN 978-0-07-025734-4.
- R.G. Lerner; G.L. Trigg (2005). *Encyclopaedia of Physics* (2nd ed.). VHC Publishers, Hans Warlimont, Springer. pp. 12–13. ISBN 978-0-07-025734-4.
- C.B. Parker (1994). *McGraw Hill Encyclopaedia of Physics* (https://archive.org/details/mcgrawhillencycl1993park) (2nd ed.). McGraw Hill. ISBN 0-07-051400-3.
- P.A. Tipler; G. Mosca (2008). *Physics for Scientists and Engineers: With Modern Physics* (6th ed.). W.H. Freeman and Co. ISBN 978-1-4292-0265-7.
- L.N. Hand; J.D. Finch (2008). *Analytical Mechanics*. Cambridge University Press. ISBN 978-0-521-57572-0.

- T.B. Arkill; C.J. Millar (1974). *Mechanics, Vibrations and Waves*. John Murray. ISBN 0-7195-2882-8.
- H.J. Pain (1983). *The Physics of Vibrations and Waves* (3rd ed.). John Wiley & Sons. ISBN 0-471-90182-2.
- J.R. Forshaw; A.G. Smith (2009). *Dynamics and Relativity*. Wiley. ISBN 978-0-470-01460-8.
- G.A.G. Bennet (1974). *Electricity and Modern Physics* (2nd ed.). Edward Arnold (UK). ISBN 0-7131-2459-8.
- I.S. Grant; W.R. Phillips; Manchester Physics (2008). *Electromagnetism* (https://archive.org/details/electromagnetism0000gran) (2nd ed.). John Wiley & Sons. ISBN 978-0-471-92712-9.
- D.J. Griffiths (2007). *Introduction to Electrodynamics* (3rd ed.). Pearson Education, Dorling Kindersley. ISBN 978-81-7758-293-2.

Further reading

- L.H. Greenberg (1978). *Physics with Modern Applications* (https://archive.org/details/physicswithmoder0000gree). Holt-Saunders International W.B. Saunders and Co. ISBN 0-7216-4247-0.
- J.B. Marion; W.F. Hornyak (1984). *Principles of Physics*. Holt-Saunders International Saunders College. ISBN 4-8337-0195-2.
- A. Beiser (1987). *Concepts of Modern Physics* (4th ed.). McGraw-Hill (International). ISBN 0-07-100144-1.
- H.D. Young; R.A. Freedman (2008). *University Physics – With Modern Physics* (12th ed.). Addison-Wesley (Pearson International). ISBN 978-0-321-50130-1.