Fundamental Constants

Atomic Mass Unit	u	$1.660\ 540\ 2(10) \times 10^{-27}$ kg $931.434\ 32(28)\ \mathrm{MeV}/c^2$
Avogadro's number	N_A	$6.022\ 136\ 7(36) \times 10^{23}\ (\mathrm{g\ mol})^{-1}$
Bohr magneton	μ_B	$9.274\ 015\ 4(31) \times 10^{-24}$ J/T
Bohr radius	a_0	$0.529\ 177\ 249(24) \times 10^{-10}$ m
Boltzmann's constant	k	$1.380\ 658(12) \times 10^{-23}$ J/K
Compton wavelength	λ_C	$2.426\ 310\ 58(22) \times 10^{-12}$ m
Deuteron mass	m_d	$3.343\ 586\ 0(20) \times 10^{-27}$ kg $2.013\ 553\ 214(24)$ u
Electron mass	m_e	$9.109\ 389\ 7(54) \times 10^{-31}$ kg $5.485\ 799\ 03(13) \times 10^{-4}$ u $0.510\ 999\ 06(15)\ \mathrm{MeV}/c^2$
Electron-volt	eV	$1.602\ 177\ 33(49) \times 10^{-19}$ J
Elementary charge	e	$1.602\ 177\ 33(49) \times 10^{-19}$ C
Gas constant	R	$8.314\ 510(70)$ J/K · mol
Gravitational constant	G	$6.672\ 59(85) \times 10^{-11}\ \mathrm{N \cdot m^2/kg^2}$
Hydrogen ground state	E_0	$13.605\ 698(40)$ eV
Josephson frequency-voltage ratio	$\frac{2e}{h}$	$4.835\ 976\ 7(14) \times 10^{14}$ Hz/V

Magnetic flux quantum	ϕ_0	2.067 834 61(61) × 10^{-15} Wb
Neutron mass	m_n	1.647 928 6(10) × 10^{-27}kg 1.008 664 904(14) u 939.565 63(28) MeV/c^2
Nuclear magneton	μ_n	5.050 786 6(17) × 10^{-27} J/T
Permeability of free space	μ_0	4л × 10^{-7} N/A^2 (exact)
Permittivity of free space	ϵ_0	8.854 187 817 × 10^{-12} C^2/N·m^2 (exact)
Planck's constant	h $\hbar$	6.626 075(40) × 10^{-34} J·s 1.054 572 66(63) × 10^{-34}J·s
Proton mass	m_p	1.672 623(10) × 10^{-27}kg 1.007 276 470(12) u 938.272 3(28) MeV/c^2
Quantized Hall resistance	h/e^2	25812.805 6(12)Ω
Rydberg constant	R_H	1.097 373 153 4(13) × 10^7 m^{-1}
Speed of light in vacuum	c	2.997 924 58 × 10^8 m/s (exact)

Commonly Used Formulas with Description

Electric Fields

1. $F = k\frac{|q_1||q_2|}{r^2}$, electric force between two charges

   Where

   $k \cong 9.0 \times 10^9\ N \cdot {m^2}/{C^2}$, Coulomb constant

   Or

   $k = \frac{1}{4\pi\epsilon_0}$

2. $\vec{E} \equiv \frac{\vec{F}}{q_0}$, electric field vector

   Or

   $\vec{E} = k\frac{q}{r^2}\ \hat{r}$

3. $\vec{E} = k\sum_i \frac{qi}{r_i^2}\ \hat{r_i}$, superposition of electric fields

4. $\vec{E} = k\lim_{\Delta qi \to 0}\sum_i \frac{\Delta qi}{r_i^2}\hat{r_i} = k\int \frac{dq}{r^2}\hat{r}$, total electric field at a point in space due to an element of charge

Gauss' Law

5. $\Phi = EA = \int_{Surface} \vec{E} \cdot d\vec{A}$, electric flux

6. $\Phi_c = \oint \vec{E} \cdot d\vec{A} = \oint E_n \, dA$, net electric flux through a closed surface

7. $\Phi_c = \oint \vec{E} \cdot d\vec{A} = \frac{q_{in}}{\epsilon_0}$, Gauss' Law

   Where

   q_{in} = the charge inside the Gaussian surface

8. The following are simplified calculations from applying Gauss' Law

   a. Insulating sphere of radius R

   $\vec{E} = k\frac{Q}{r^2}\ at\ r > R$

   $\vec{E} = k\frac{Q}{R^3}r\ at\ r < R$

   b. Thin spherical shell of radius R

   $\vec{E} = k\frac{Q}{r^2}\ at\ r > R$

   $\vec{E} = o\ at\ r < R$

   c. Line charge of infinite length and charge per unit length λ

   $\vec{E} = 2k\frac{\lambda}{r}$, outside the line charge

d. Nonconducting, infinite charged plane with charge per unit area σ

$\vec{E} = \frac{\sigma}{2\epsilon_0}$, everywhere outside the plane

e. Conductor of surface charge per unit area σ

$\vec{E} = \frac{\sigma}{\epsilon_0}$, just outside the conductor

$\vec{E} = 0$, inside the conductor

Electric Potential

9. $\Delta U = -q_0 \int_A^B \vec{E} \cdot ds$, change in potential energy

10. $\Delta V = \frac{\Delta U}{q_0} = -\int_A^B \vec{E} \cdot ds$, potential difference

Where

$1V = 1^{J}/_{C}$

11. $\Delta V = -Ed$, potential difference between two points in a uniform electric field $\vec{E}$

Where

d is the displacement in the direction parallel to $\vec{E}$

12. $V = k\frac{q}{r}$, potential due to a point charge q

Where

r is the distance from the charge

13. $U = k\frac{q_1\, q_2}{r_{12}}$, potential energy of a pair of point charges separated by distance r_{12}

14. $V = K\int\frac{dq}{r}$, electric potential for a continuous charge distribution

15.

a. $E_x = \frac{-dV}{dx}$, x component of an electric field potential in a 3 dimensional system

b. $Ey = \frac{-dV}{dy}$, y component

c. $Ez = \frac{-dV}{dz}$, z component

16. The following are simplified electric potential calculations for various charge distributions.

a. Uniformly charged ring of radius a

$V = k\frac{Q}{\sqrt{x^2+a^2}}$, Along the axis of the ring, a distance x from its center.

b. Uniformly charged disk of radius a

$V = 2\pi k\sigma[\sqrt{x^2+a^2} - x]$, along the axis of the disk, a distance x from its center

c. Uniformly charged, insulating solid sphere of radius R and total charge Q

$V = k\frac{Q}{r}, at\ r\ \geq R$

$V = \frac{kQ}{2R}\left(3 - \frac{r^2}{R^2}\right), at\ r\ < R$

d. Isolated conducting sphere of total charge Q and radius R

$V = k\frac{Q}{R}, at\ r\ \leq R$

$V = k\frac{Q}{r}, at\ r\ > R$

Magnetic Fields

17. $\vec{F} = q\vec{v} \times \vec{B}$, magnetic force that acts on a charge q moving with a velocity, *v*

18. $F = qvBsin\theta$, magnitude of the magnetic force

Where

θ is the angle between $\vec{v}\ and\ \vec{B}$

and

$[B] = T = \frac{Wb}{m^2} = \frac{N}{A{\cdot}m}$

19. $\vec{F} = I\vec{l} \times \vec{B}$, The force on a conductor of length *l* carrying a current I while placed in a uniform external magnetic field $\vec{B}$

20. $d\vec{F} = I\, d\vec{s} \times \vec{B}$, force on a very small segment ds

21. $\mu = I\vec{A}$, magnetic moment of a current loop

Where,

A is perpendicular to the plane of the loop and |A| is equal to the area of the loop

22. $\tau = \mu \times \vec{B}$, torque on a current loop placed in a uniform external magnetic field.

23. $r = \frac{mv}{qB}$, the radius r of the circular path a charged particle moves in a perpendicular plan to the magnetic field.

Where,

m is the mass of the particle

24. $\omega = \frac{qB}{m}$, cyclotron frequency

25. $\vec{F} = q\vec{E} + q\vec{v} \times \vec{B}$, Lorente Force

Magnetic Field Source

26. $d\vec{B} = k_m \frac{Id\vec{s}\times\hat{r}}{r^2}$, Biot-Savart law

Where,

$$km = 10^{-7} \frac{Wb}{A \cdot m}$$

27. $B = \frac{\mu_0 I}{2\pi a}$, Magnetic field of an infinite long wire where the field lines are concentric with the wire.

28. $\frac{F}{l} = \frac{\mu_0 I1 I2}{2\pi a}$, Force per unit length between two wires.

29. $\oint \vec{B} \cdot d\vec{s} = \mu_0 I$, Ampère's Law

30. $B = \frac{\mu_0 NI}{2\pi r}$, Magnetic field inside a toroid

Where,

N= number of turns

31. $B = \mu_0 \frac{N}{l} I = \mu_0 nI$, Magnetic field inside a solenoid

32. $\Phi_m \equiv \int \vec{B} \cdot d\vec{A}$, Magnetic flux

33. $\oint \vec{B} \cdot d\vec{s} = \mu_0 I + \mu_0 I_d$, Generalized format of Ampère's Law

Where,

$I_d \equiv \in_0 \frac{d\Phi_e}{dt}$, Displacement current

Electromagnetic Waves

34. $\frac{\partial^2 E}{\partial x^2} = \mu_0 \in_0 \frac{\partial^2 E}{\partial t^2}$, property of electric field, wave equation

35. $\frac{\partial^2 B}{\partial x^2} = \mu \in_0 \frac{\partial^2 B}{\partial t^2}$, Property of magnetic field, wave equation

36. $C = \frac{1}{\sqrt{\mu_0 \in_0}} = 3.00x10^8 \, {}^{m}/_{s}$, The speed of electromagnetic waves in a vacuum

37. $\frac{E}{B} = C$, The instantaneous magnitudes of $|\vec{E}|$ and $|\vec{B}|$ in an electromagnetic wave are related by this expression.

38. $\vec{S} \equiv \frac{1}{\mu_0} \vec{E} \times \vec{B}$, Poynting vector, the rate of flow of energy, in electromagnetic waves, crossing a unit area.

39. $P = \frac{S}{c}$, Pressure exerted by electromagnetic on incident surface under complete absorption.

40. $E = E_m \cos(kx - \omega t)$, electric field of a sinusoidal plane wave propagating in the positive direction along x axis.

41. $B = B_m \cos(kx - \omega t)$, magnetic field of a sinusoidal plane wave propagating in the positive direction along x axis.

Since ω = 2ωf and k= 2л/λ, we find that

42. $\frac{\omega}{k} = \lambda f = c$

43. $S_{av} = \frac{E_m B_m}{2\mu_0} = \frac{E_m{}^2}{2\mu_0 C} = \frac{C}{2\mu_0} B_m{}^2$, The average value of a Poynting vector for a plane electromagnetic wave.

<u>Superconductivity</u>

44. $B_c(T) = B_c(0)[1 - \left(\frac{T}{T_c}\right)^2]$, Critical magnetic field as a function of temperature, T, for type I superconductor (sc).

Where,

T_c = Critical Temperature of a given sc

45. $\vec{M} = \frac{-\vec{B}}{\mu_0} = x\vec{B}$, magnetization of an SC exposed to magnetic field, $\vec{B}$

Where,

$x = {-1}/{\mu_0}$, magnetic susceptibility

46. $E_g = 3.53\ kT_c$, Energy gap of an SC representing the energy required to break up one Cooper pair which is proportional to the critical temperature at T=0K

Courtesy of Serway, Physics for Scientists and Engineers