Handbook of Physics

Department of Physics, RVCE, Bengaluru

For course:
Condensed Matter Physics for Engineers

Fundamental Constants

All the constants in this table are taken from *The NIST Reference on Constants, Units & Uncertainty* found in `http://physics.nist.gov/constants`.

Quantity	Symbol	Value	Unit
Speed of light in vacuum	c	299 792 458	$\mathrm{m\,s^{-1}}$
Magnetic constant	μ_0	$4\pi \times 10^{-7}$	$\mathrm{N\,A^{-2}}$
Electric constant $1/\mu_0 c^2$	ϵ_0	$8.854\,187\,817 \times 10^{-12}$	$\mathrm{F\,m^{-1}}$
Newtonian constant of gravitation	G	$6.673\,84 \times 10^{-11}$	$\mathrm{m^3kg^{-1}s^{-2}}$
Planck constant	h	$6.626\,069\,57 \times 10^{-34}$	$\mathrm{J\,s}$
$h/2\pi$	$\hbar$	$1.054\,571\,726 \times 10^{-34}$	$\mathrm{J\,s}$
Elementary charge	e	$1.602\,176\,565 \times 10^{-19}$	C
Bohr magneton $e\hbar/2m_e$	μ_B	$927.400\,968 \times 10^{-26}$	$\mathrm{J\,T^{-1}}$
Nuclear magneton $e\hbar/2m_p$	μ_N	$5.050\,783\,53 \times 10^{-27}$	$\mathrm{J\,T^{-1}}$
Fine-structure constant $e^2/4\pi\epsilon_0\hbar c$	α	$7.297\,352\,569\,8 \times 10^{-3}$	
Rydberg constant $\alpha^2 m_e c/2h$	R_∞	10 973 731.568 539	$\mathrm{m^{-1}}$
Bohr radius $\alpha/4\pi R_\infty = 4\pi\epsilon_0\hbar^2/m_e e^2$	a_0	$0.529\,177\,210\,92 \times 10^{-10}$	m
Electron mass	m_e	$9.109\,382\,91 \times 10^{-31}$	kg
energy equivalent	$m_e c^2$	0.510 998 928	MeV
Proton mass	m_p	$1.672\,621\,777 \times 10^{-27}$	kg
energy equivalent	$m_p c^2$	938.272 046	MeV
Neutron mass	m_n	$1.674\,927\,351 \times 10^{-27}$	kg
energy equivalent	$m_n c^2$	939.565 379	MeV

Quantity	Symbol	Value	Unit
Avogadro constant	N_A	$6.022\,141\,29 \times 10^{23}$	$\mathrm{mol^{-1}}$
Atomic mass constant $m_u = \frac{1}{12}m(^{12}C) = 1u$	m_u	$1.660\,538\,921 \times 10^{-27}$	kg
energy equivalent	$m_u c^2$	$1.492\,417\,954 \times 10^{-10}$	J
		931.494 061	MeV
Faraday constant $N_A e$	F	96 485.336 5	$\mathrm{C\,mol^{-1}}$
Universal gas constant	R_u	8.314 462 1	$\mathrm{J\,mol^{-1}K^{-1}}$
Boltzmann constant R/N_A	k	$1.380\,648\,8 \times 10^{-23}$	$\mathrm{J\,K^{-1}}$
Stefan-Boltzmann constant $(\pi^2/60)k^4/\hbar^3c^2$	σ	$5.670\,373 \times 10^{-8}$	$\mathrm{W\,m^{-2}K^{-4}}$
First radiation constant $2\pi hc^2$	c_1	$3.741\,771\,53 \times 10^{-16}$	$\mathrm{W\,m^2}$
Second radiation constant hc/k	c_2	$1.438\,777\,0 \times 10^{-2}$	$\mathrm{m\,K}$
Wien displacement law			
constant $b = \lambda_{max}T$	b	$2.897\,772\,1 \times 10^{-3}$	$\mathrm{m\,K}$
constant $b' = \nu_{max}/T$	b'	$5.878\,925\,4 \times 10^{10}$	$\mathrm{Hz\,K^{-1}}$
Molar mass constant	M_u	1×10^{-3}	$\mathrm{kg\,mol^{-1}}$
Molar mass of ^{12}C	$M(^{12}C)$	12×10^{-3}	$\mathrm{kg\,mol^{-1}}$
Standard atmosphere		101.325	k Pa
Standard acceleration of gravity	g	9.806 65	$\mathrm{m\,s^{-2}}$

Quantum Mechanics

Quantity	Formula	Glossary
Planck's formula for the blackbody radiation: Power radiated per unit area per unit solid angle per unit frequency by a black body at temperature T:	$U(\nu, T) = \dfrac{8\pi h\nu^3/c^3}{\left[\exp\left(\frac{h\nu}{kT}\right) - 1\right]}$	h = Planck constant c = speed of light in vacuum k = Boltzmann constant ν = frequency of the electromagnetic radiation

Einstein's fundamental equation for photoelectric effect:	$E_K = h\nu - \Phi$	E_K = kinetic energy of the ejected electron ν = frequency of photon Φ = work function of the metal
Energy of the discrete emission or absorption of radiation by atoms:	$h\nu = \lvert E_i - E_f \rvert$	E_i = initial state energy E_f = final state energy
Energy of the emitted photon:	$E = h\nu = \dfrac{hc}{\lambda}$	λ = wavelength of the emitted photon
Compton formula:	$\lambda' - \lambda = \dfrac{h}{m_e c}(1 - \cos\theta)$	λ = wavelength of the incident photon λ' = wavelength after scattering m_e = electron rest mass c = speed of light θ = scattering angle
Compton wavelength of the electron:	$\lambda_e = \dfrac{h}{m_e c} = 2.43 \times 10^{-12}$ m	
Compton formula in terms of the energies:	$E_{\gamma'} = \dfrac{E_\gamma}{1 + \frac{E_\gamma}{m_e c^2}(1 - \cos\theta)}$	$E_\gamma = hc/\lambda$ = incident energy $E_{\gamma'}$ = scattered photon energy
de Broglie wavelength:	$\lambda = \dfrac{h}{p}$ $\lambda = \dfrac{h}{\sqrt{2mqV}}$	p = momentum of the particle m = mass of the particle q = charge of the particle V = potential with which the particle is accelerated
Phase velocity:	$v_p = \dfrac{\omega}{k} = \nu\lambda$	ω = angular frequency $k = 2\pi/\lambda$ = wave number ν = frequency
Group velocity:	$v_g = \dfrac{d\omega}{dk}$	

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Relation between group velocity and phase velocity:	$v_g = v_p - \dfrac{2\pi}{k}\left(\dfrac{dv_p}{d\lambda}\right)$	
Heisenberg uncertainty relationships:	$\Delta x \Delta p_x \geq \dfrac{h}{4\pi}$ $\Delta E \Delta t \geq \dfrac{h}{4\pi}$ $\Delta J \Delta\theta \geq \dfrac{h}{4\pi}$	Δx, Δp_x, ΔE, Δt, ΔJ and $\Delta\theta$ are the uncertainties in the measurement of the position, momentum, energy, time, angular momentum and angular position respectively.
Time independent Schrödinger wave equation in one dimension:	$\dfrac{d^2\psi}{dx^2} + \dfrac{8\pi^2 m}{h^2}(E - V)\psi = 0$	$\psi \equiv \psi(x)$ = wave function E = total energy V = potential energy
Probability density:	$P(x,t) = \Psi^*\Psi = \lvert\Psi(x,t)\rvert^2$	
Normalization condition:	$\int_x \lvert\Psi(x,t)\rvert^2\, dx = 1$	
Schrödinger equation in operator form:	$\hat{H}\psi = E\psi$	$\hat{H}$ = Hamiltonian operator
Particle in one-dimensional potential well of infinite depth:		
a) Differential equation:	$\dfrac{d^2\psi}{dx^2} + k^2\psi = 0$ $k^2 = \dfrac{8m\pi^2 E}{h^2}$	
b) Solution:	$\psi = A\cos(kx) + B\sin(kx)$	
c) Energy eigen values:	$E = \dfrac{n^2 h^2}{8ma^2}$ $n = 1, 2, 3\ldots$	a = width of the well
d) Normalized wave function:	$\psi_n = \sqrt{\dfrac{2}{a}}\sin\left(\dfrac{n\pi}{a}x\right)$	

Electrical Conductivity in Solids and Band Theory of Solids

Quantity	Formula	Glossary
Ohm's Law:	$V = IR$	V = voltage applied I = current flowing R = resistance A = area of cross-section L = length of the material n = carrier concentration e = electronic charge v_d = drift velocity m = mass of the electron τ =mean collision time
Resistivity:	$\rho = \frac{RA}{L}$	
Conductivity:	$\sigma = \frac{1}{\rho} = \frac{L}{RA}$	
Electric field:	$E = \frac{V}{L}$	
Current density:	$J = \frac{I}{A} = \sigma E$	
Electric current in a conductor:	$I = nev_d A$	
Drift velocity:	$v_d = \frac{eE}{m}\tau$	
Electrical conductivity of a conductor:	$\sigma = \frac{ne^2\tau}{m}$	
Mobility of electrons:	$\mu = \frac{v_d}{E} = \frac{e\tau}{m}$	
Fermi factor:	$f(E) = \frac{1}{1+\exp\left(\frac{E-E_F}{kT}\right)}$	E = energy level E_F = Fermi level k = Boltzmann constant T = temperature of the material
Density of states in a material in the energy range E & $E+dE$:	$g(E)dE = \frac{4\pi}{h^3}(2m)^{3/2}E^{1/2}dE$	
Number of free electrons per unit volume in the energy range E & $E+dE$:	$N(E)\,dE = g(E)f(E)\,dE$	
Total number of free electrons per unit volume in metals:	$n = \frac{8\pi}{3h^3}(2m)^{3/2}E_F^{3/2}$	m = mass of the electron

Fermi energy at 0 K:	$E_F = \frac{h^2}{8m}\left(\frac{3n}{\pi}\right)^{2/3}$	
Carrier concentration in intrinsic semiconductor:		N_C and N_V are effective density of states in the conduction and valence band. m_e^* = effective mass of electron in the material m_h^* = effective mass of hole in the material E_C = lowest energy level in the conduction band E_V = is the highest energy level in the valence band E_g = is the energy gap
a) for electrons:	$n = N_C e^{-(E_C-E_F)/kT}$ $N_C = 2\left[\frac{2\pi m_e^* kT}{h^2}\right]^{3/2}$	
b) for holes:	$p = N_V e^{-(E_F-E_V)/kT}$ $N_V = 2\left[\frac{2\pi m_h^* kT}{h^2}\right]^{3/2}$	
Fermi level in intrinsic semiconductor:	$E_F = \left(\frac{E_C+E_V}{2}\right) + \frac{3}{4}kT\ln\left(\frac{m_h^*}{m_e^*}\right)$	
a) For small kT:	$E_F = \frac{E_C+E_V}{2}$	
b) With $E_C - E_V = E_g$:	$E_F = \frac{E_g}{2} + E_V$	
Intrinsic charge carrier concentration:	$n_i = \sqrt{np} = 2\left(\frac{2\pi k}{h^2}\right)^{3/2}(m_e^* m_h^*)^{3/4}T^{3/2}e^{-E_g/2kT}$	
Conductivity of an intrinsic semiconductor:	$\sigma_i = en_i(\mu_e + \mu_h)$	μ_e = mobility of electrons μ_h = mobility of holes
Fermi energy for extrinsic semiconductors:		N_d = donor concentration N_a = acceptor concentration
a) n-type	$E_{F_n} = \frac{E_C+E_D}{2} - \frac{kT}{2}\ln\frac{N_C}{N_d}$	
b) p-type	$E_{F_p} = \frac{E_V+E_A}{2} + \frac{kT}{2}\ln\frac{N_V}{N_a}$	
Law of Mass Action:	$np = n_i^2$ = constant	

Hall voltage:	$V_H = R_H \frac{BI}{t}$	R_H = Hall coefficient B = applied magnetic field I = current flowing t = thickness of the material
Hall coefficient:		
a) For metals and n-type semiconductors:	$R_H = \frac{-1}{ne}$	
b) For p-type semiconductors:	$R_H = \frac{1}{pe}$	

Semiconductor Devices

Quantity	Formula	Glossary
Internal Potential barrier:	$V_0 = \frac{kT}{e} \ln\left(\frac{N_D N_A}{n_i^2}\right)$	k = Boltzmann constant T = temperature e = electronic charge N_D = donors concentration N_A = acceptors concentration
The diode equation:	$I = I_0\left[\exp\left(\frac{eV}{kT}\right) - 1\right]$	n_i = intrinsic carrier concentration V = voltage across the diode I = current through the diode I_0 = reverse saturation current E_g = energy gap I_E = emitter current I_B = base current I_C = collector current
Wavelength of light emitted by LED:	$\lambda = \frac{h\nu}{E_g}$	
Relation between currents in a transistor:	$I_E = I_B + I_C$	
Common base current gain factor:	$\alpha_{dc} = \frac{I_C}{I_E}$	
Common emitter dc current gain:	$\beta_{dc} = \frac{I_C}{I_B}$	
Voltage gain of an amplifier:	$\text{Gain} = \frac{\text{Output Voltage}}{\text{Input Voltage}}$	

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Dielectrics and Transducers

Quantity	Formula	Glossary
Dipole moment of two charges $-q$ and $+q$:	$\mu = (2a)q$	$2a$ distance between the charges α = polarizability E = applied electric field V = volume of the dielectric
Induced dipole moment:	$\mu = \alpha E$	
Torque on the dipole in an electric field:	$\tau = qE2a\sin\theta = \mu E\sin\theta$	
Polarization (total dipole moment / unit volume):	$P = \frac{\mu_{\text{total}}}{V}$	
Electric displacement:	$D = \epsilon_0 \epsilon_r E$	ϵ_0 = permittivity of free space ϵ_r = relative permittivity
Relation for dielectric susceptibility, χ, for linear dielectrics:	$P = \chi \epsilon_o E$	
Relation between ϵ_r and χ:	$\epsilon_r = 1 + \chi$	
Electronic or Atomic Polarization:	$P_e = N\alpha_e E$	N = number of atoms per unit volume α_e = electronic polarizability α_i = ionic polarizability k = Boltzmann constant T = temperature μ = dipole moment
Electronic polarizability:	$\alpha_e = \frac{\epsilon_0(\epsilon_r - 1)}{N}$	
Ionic Polarization:	$P_i = N\alpha_i E$	
Orientation or dipole Polarization:	$P_o = \frac{N\mu^2 E}{3kT}$	
Orientation polarizability:	$\alpha_o = \frac{\mu^2}{3kT}$	
Internal field in a solid for one dimensional infinite array of dipoles:	$E_i = E + \frac{1.2\mu}{\pi\epsilon_0 d^3}$	d = thickness of the dielectric slab
Clausius Mosotti equation:	$\frac{\epsilon_r - 1}{\epsilon_r + 2} = \frac{N\alpha_e}{3\epsilon_0}$	

Piezoelectric transducer formula: The charge generated Q is given by,		F = applied force d = piezoelectric coefficient of the crystal ($d_{\text{quartz}} = 2.3 \times 10^{-12}$ C/N) b/a = thickness/width
a) For longitudinal arrangement:	$Q = Fd$	
b) For transverse arrangement:	$Q = Fd(b/a)$	

Lasers

Quantity	Formula	Glossary
Boltzmann factor:	$\frac{N_2}{N_1} = e^{-h\nu/kT}$	h = Planck constant k = Boltzmann constant T = temperature ν = frequency of the electromagnetic radiation $A = A_{21}$ $B = B_{21}$ λ = wavelength
Einstein's coefficients:	$\frac{A_{21}}{B_{21}} = \frac{8\pi h\nu^3}{c^3}$ $B_{12} = B_{21}$	
Energy density at thermal equilibrium:	$U(\nu, T) = \frac{A}{B} \frac{1}{\exp\left(\frac{h\nu}{kT}\right) - 1}$	
Length of the resonator cavity:	$L = n\frac{\lambda}{2}, \quad n = 1, 2, 3, \ldots$	

Optical Fibers

Quantity	Formula	Glossary
Snell's law:	$n_1 \sin\theta_1 = n_2 \sin\theta_2$	n_1 and n_2 are the refractive indices. θ_1 and θ_2 are angle of incidence & refraction. c and v are velocities of light in vacuum and the medium.
Absolute refractive index:	$n = \frac{c}{v}$	

Numerical aperture:	$\text{NA} = \sin\theta_0 = \frac{\sqrt{n_1^2 - n_2^2}}{n_0}$	θ_0 = acceptance angle n_0, n_1 and n_2 are the refractive indices of surrounding medium, core and cladding.
Fraction Index Change:	$\Delta = \frac{n_1 - n_2}{n_1}$	
Relation between NA and Δ:	$\text{NA} = n_1\sqrt{2\Delta}$	
V-number if surrounding medium is air:	$V = \frac{\pi d}{\lambda}\text{NA}$	d = core diameter λ = wavelength of light
Number of modes for step index fiber:	$\approx \frac{V^2}{2}$	
Number of modes for graded index fiber:	$\approx \frac{V^2}{4}$	
Attenuation co-efficient (loss per unit length):	$\alpha = -\frac{10}{L}\log\left(\frac{P_{\text{out}}}{P_{\text{in}}}\right)$	P_{out} = output power P_{in} = input power L = length of the optical fiber

□