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Handbook of Physics

For courses:
Classical Physics for Engineers
Applied Physics for Engineers
Quantum Physics for Engineers
Condensed Matter Physics for Engineers

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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
Avogadro constant	N_A	$6.022\,141\,29 \times 10^{23}$	$\mathrm{mol^{-1}}$
Atomic mass constant $m_u = \frac{1}{12}m(^{12}\mathrm{C}) = 1\mathrm{u}$	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	$\mathrm{J\,mol^{-1}K^{-1}}$

Quantity	Symbol	Value	Unit
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 $b = \lambda_{\mathrm{max}}T$	b	$2.897\,772\,1 \times 10^{-3}$	$\mathrm{m\,K}$
constant $b' = \nu_{\mathrm{max}}/T$	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	$M(^{12}\mathrm{C})$	12×10^{-3}	$\mathrm{kg\,mol^{-1}}$
Standard atmosphere		101.325	k Pa
Standard acceleration of gravity	g	9.806 65	$\mathrm{m\,s^{-2}}$

Kinematics and Kinetics

Quantity	**Formula**	**Glossary**
Velocity:	$v = \frac{ds}{dt}$	s = displacement t = time
Acceleration:	$a = \frac{d^2s}{dt^2}$	
Momentum:	$p = mv$	m = mass of the object
Newton's II law:	$F = \frac{dp}{dt} = ma$	F = force acting
Equations of motion with uniform acceleration:	$v = u + at$ $s = ut + \frac{1}{2}at^2$ $v^2 - u^2 = 2as$	v = final velocity u = initial velocity

Uniform circular motion:		
a) Angular velocity:	$\omega = \dfrac{d\theta}{dt}$	θ = angular displacement
b) Relation between v and ω:	$v = r\omega$	r = radius
c) Time period:	$T = 2\pi/\omega$	
d) Angular acceleration:	$\alpha = \dfrac{d\omega}{dt} = \dfrac{d\omega}{d\theta}\omega$	
e) Linear acceleration:	$a = \alpha r$	
f) Equations of motion:	$\omega = \omega_0 + \alpha t$ $\theta = \omega_0 t + \dfrac{1}{2}\alpha t^2$ $\omega^2 - \omega_0^2 = 2\alpha\theta$	ω_0 = initial angular velocity
g) Relations in terms of revolutions per minute (RPM) N:	$\omega = \dfrac{2\pi N}{60}$, $v = \omega r = \dfrac{2\pi N}{60} r$	
Superelevation:		
a) Centripetal force *or* centrifugal force:	$F = m\dfrac{v^2}{r}$	v = velocity, m = mass r = path radius
b) Frictional force:	$F = fW$	$W = mg$ = weight
c) Condition for skidding on level road:	$v = \sqrt{fgr}$	f = coefficient of friction
d) Condition for over turning on level road:	$v = \sqrt{\dfrac{grB}{2h}}$	g = acceleration due to gravity B = distance between inner and outer wheels
e) Condition for skidding on banked road:	$v = \sqrt{gr\left(\dfrac{f + \tan\theta}{1 - f\tan\theta}\right)}$	h = height of center of gravity from ground
f) Condition for overturning on banked road:	$v = \sqrt{gr\left(\dfrac{B + 2h\tan\theta}{2h - B\tan\theta}\right)}$	θ = angle of superelevation

g) Reactions of a vehicle moving on a level circular path:	$R_A = \frac{W}{2}\left(1 - \frac{v^2 h}{Bgr}\right)$ $R_B = \frac{W}{2}\left(1 + \frac{v^2 h}{Bgr}\right)$	
h) Expression for superelevation, e:	$e = \frac{E}{B} = \tan\theta$ $e = \tan\theta = \frac{v^2}{gr}$	E = height from ground to elevated end of the road
i) Superelevation, e for rails:	$e = \frac{E}{G}$	G = gauge of rails
Projectile motion:		
a) Equation to the path of projectile:	$y = x\tan\alpha - \frac{gx^2}{2u^2\cos^2\alpha}$	α = angle of projection u = velocity of projection
b) Horizontal range:	$R = \frac{u^2\sin(2\alpha)}{g},\ R_{\max} = \frac{u^2}{g}$	
c) Time of flight:	$T = \frac{2u\sin\alpha}{g}$	
d) Maximum height:	$H = \frac{u^2\sin^2\alpha}{2g}$	

Oscillations

Quantity	Formula	Glossary
Frequency:	$f = \frac{1}{T}$	T = time period
Angular frequency:	$\omega = \frac{2\pi}{T} = 2\pi f$	
Differential equation of a Simple Harmonic Motion (SHM):	$\frac{d^2y}{dt^2} + \omega^2 y = 0$	y = displacement

Equation of motion for a particle under linear SHM:	$y(t) = y_0 \sin(\omega t + \phi)$ or $y(t) = y_0 \cos(\omega t + \phi)$	y_0 = amplitude ϕ = phase
Velocity and acceleration for a particle under SHM:	$v = \omega\sqrt{y_0^2 - y^2}$ $a = -\omega^2 y$	
Time period of a spring-mass system undergoing SHM:	$T = \frac{\omega}{2\pi} = 2\pi\sqrt{\frac{m}{k}}$	m = mass attached k = spring constant
Spring constant in stretching due to load mg	$k = \frac{mg}{L}$	L = stretching length g = acceleration due to gravity
Effective spring constant for springs in series:	$\frac{1}{k_{\text{eff}}} = \frac{1}{k_1} + \frac{1}{k_2} + \frac{1}{k_3} + \cdots$	
Effective spring constant for springs in parallel:	$k_{\text{eff}} = k_1 + k_2 + k_3 + \cdots$	
Damped harmonic oscillator:		
a) Differential equation:	$\frac{d^2y}{dt^2} + 2b\frac{dy}{dt} + \omega^2 y = 0$	r = damping constant $2b = r/m$
b) General solution:	$y = A_1 e^{\left(-b+\sqrt{b^2-\omega^2}\right)t}$ $+A_2 e^{\left(-b-\sqrt{b^2-\omega^2}\right)t}$	$\omega^2 = k/m$
c) Solution for critically damped case ($b^2 \approx \omega^2$):	$y = \big[(C+D)+$ $\beta t(C-D)\big]e^{-bt}$	$\beta = \sqrt{b^2 - \omega^2}$
d) Solution for low damping case ($b^2 < \omega^2$):	$y = Ae^{-bt}\sin(\beta' t + \phi)$	$\beta' = \sqrt{\omega^2 - b^2}$
e) For this case the time period and the frequency is given by,	$T = \frac{2\pi}{\beta'} = \frac{2\pi}{\sqrt{\omega^2 - b^2}}$ $f = \frac{1}{T} = \frac{1}{2\pi}\sqrt{\frac{k}{m} - \frac{r^2}{4m^2}}$	

Forced Vibrations:		
a) Differential equation:	$$\frac{d^2y}{dt^2} + 2b\frac{dy}{dt} + \omega^2 y = f\sin(\omega_d t)$$	$f = F_0/m$ F_0 = amplitude of the external driving force ω_d = angular frequency of the external force
b) General solution:	$$y = A\sin(\omega_d t - \phi)$$	
c) Amplitude A and phase ϕ:	$$A = \frac{f}{\sqrt{\left(\omega^2 - \omega_d^2\right)^2 + 4b^2\omega_d^2}}$$ $$\tan\phi = \frac{2b\omega_d}{\omega^2 - \omega_d^2}$$	
d) Amplitude at resonance: $(\omega = \omega_d)$	$$A_{\max} = \frac{f}{2b\omega_d}$$	

Elasticity

Quantity	Formula	Glossary
Linear strain or Tensile strain:	$$= \frac{\text{change in length}}{\text{original length}} = \frac{\Delta L}{L}$$	Δx = deformation F = applied force A = cross-sectional area
Volume strain or Bulk strain:	$$= \frac{\text{change in volume}}{\text{original volume}} = \frac{\Delta V}{V}$$	
Shear strain:	$$= \theta = \frac{\Delta x}{L}$$	
Stress:	$$\text{Stress} = \frac{F}{A}$$	
Hooke's law:	stress $\propto$ strain $$\frac{\text{stress}}{\text{strain}} = \text{modulus of elasticity}$$	

Young's modulus (Y):	$Y = \frac{\text{Normal stress}}{\text{Longitudin al strain}}$ $= \frac{FL}{A\,\Delta L}$	
Bulk modulus (K):	$K = \frac{\text{Normal stress}}{\text{Volume strain}}$ $= \frac{FV}{A\,\Delta V}$	
Rigidity modulus (η):	$\eta = \frac{\text{Tangential stress}}{\text{Shearing strain}}$ $= \frac{FL}{A\,\Delta x}$	
Poisson's Ratio (σ):	$\sigma = \frac{\text{lateral strain}}{\text{longitudinal strain}}$ $= \frac{L}{\Delta L}\frac{\Delta D}{D}$	D = original diameter ΔD = change in diameter
Relations between different modulus of elasticity	$Y = \frac{1}{\alpha}$ $K = \frac{1}{3(\alpha - 2\beta)}$ $\eta = \frac{1}{2(\alpha + \beta)}$ $\sigma = \frac{\beta}{\alpha}$	α = elongation per unit length per unit stress along the direction of the force β = contraction per unit length per unit stress along the direction $\perp$ to the force
Relations between Young's modulus Y and bulk modulus K:	$K = \frac{Y}{3(1 - 2\sigma)}$	
Relations between Young's modulus Y and rigidity modulus η:	$\eta = \frac{Y}{2(1 + \sigma)}$	
Relations between Young's modulus Y, bulk modulus K and rigidity modulus η:	$Y = \frac{9\eta K}{3K + \eta}$	

Single cantilever:		
a) Bending moment for the beam bent to a radius of curvature of R:	$= \frac{Y}{R} I_g$	A = area of cross section of the beam k = radius of gyration about the neutral axis W = load L = length of the beam δ = depression produced at loaded end
b) Geometrical moment of inertia:	$I_g = Ak^2$	
c) Depression produced at a distance x from the fixed end:	$y = \frac{W}{YI_g}\left[\frac{Lx^2}{2} - \frac{x^3}{6}\right]$	
d) Young's modulus of the material of the cantilever:	$Y = \frac{WL^3}{3\delta I_g}$	
e) For beam with rectangular cross section	$I_g = \frac{bd^3}{12}$	b = breadth d = thickness
f) For beam with circular cross section	$I_g = \frac{\pi r^4}{4}$	r = radius
Couple per unit twist of a cylindrical rod (or wire):	$C = \frac{\pi \eta R^4}{2L}$	R = cross-sectional radius of the cylinder L = length of the wire I = moment of inertia of the attached rigid body about the axis of rotation
Time period of a torsional pendulum:	$T = 2\pi\sqrt{\frac{I}{C}}$	
Rigidity modulus of the wire of a torsional pendulum:	$\eta = \frac{8\pi L}{R^4}\left(\frac{I}{T^2}\right)$	

Thermodynamics

Quantity	Formula	Glossary
Constant volume gas thermometer:	$T = 273.16\,\mathrm{K}\,\frac{P}{P_t}$	T = temperature determined P = gas pressure measured P_t = gas pressure at triple point of water

Fahrenheit scale	$F = \frac{9}{5}C + 32$	C = Celsius scale
Pressure measured by a open U-tube mercury manometer:	$P = P_0 + \rho g z$ $= \rho g z_0 + \rho g z$ $= \rho g (z_0 + z)$	P_0 = atmospheric pressure ρ = density of mercury g = acceleration due to gravity z = difference in height of mercury in the two limbs z_0 = barometer reading
Heat energy required to raise the temperature of a liquid or a solid by ΔT:	$\Delta Q = mC\Delta T$	m = mass of the substance C = specific heat
First law of thermodynamics:	$Q = \Delta U + W$	Q = heat transferred to the system ΔU = change in internal energy of the system W = work done by the system
Ideal gas equation of state:	$PV = nR_uT$ $PV = mRT$ $m = nM$ $R = R_u/M$	P = pressure V = volume n = number of moles R_u = universal gas constant T = temperature M = molecular weight m = mass of the gas R = gas constant
Work done by gas expansion:	$W = \int_{V_i}^{V_f} P dV$	V_i = initial volume V_f = final volume
Work done in a isobaric process:	$W = P(V_f - V_i) = P\Delta V$	

Work done in a isothermal process:	$W = mRT\ln\left(\frac{V_f}{V_i}\right)$	
Adiabatic equation of state:	$PV^{\gamma} = \text{constant}$	$\gamma = C_P/C_V$ C_P = specific heat at constant pressure C_V = specific heat at constant volume $C_P - C_V = R$
Work done in adiabatic expansion of gases:	$W = \frac{1}{\gamma - 1}(P_iV_i - P_fV_f)$	P_i, V_i, P_f, V_f are initial and final pressures and volumes respectively.

Fluid Mechanics I

Quantity	Formula	Glossary
Specific volume:	$V_\rho = \frac{V_m}{m} = \frac{1}{\rho}$	V_m = volume of the fluid m = mass of the fluid ρ = density of the fluid
Specific gravity:	$\text{SG} = \frac{\rho}{\rho_\text{w}}$	$\rho_\text{w} = 1000\ \text{kg/m}^3$ is the density of water at 4°C.
Newton's law of viscosity for one-dimensional shear flow of Newtonian fluids:	$\tau = \mu\frac{du}{dy}$	τ = shear stress μ = absolute viscosity du/dy = velocity gradient
The force F required to move the upper plate at a constant speed of V while the lower plate remains stationary:	$F = \mu A\frac{V}{l}$	A = contact area between the plate and the fluid l = distance between the two parallel plates
Kinematic viscosity:	$\nu = \frac{\mu}{\rho}$	

Torque required in concentric cylinders rotational viscometer:	$$T = \mu \frac{4\pi^2 R^3 \dot{n} L}{l}$$	L = length of the cylinder $\dot{n}$ = number of revolutions per unit time R = radius of the inner cylinder l = fluid layer thickness within a small gap between two concentric cylinders P = pressure on the fluid ρ = density of the liquid c = velocity of the sound waves through the liquid $\gamma = c_p/c_v$ is the specific heat ratio of the fluid $\gamma = 1$ for liquids
Bulk modulus of elasticity for fluids: (in Pa)	$$\kappa = -V_\rho \left(\frac{\partial P}{\partial V_\rho}\right)_T = \rho \left(\frac{\partial P}{\partial \rho}\right)_T$$	
Isothermal compressibility: (in Pa^{-1})	$$\alpha = \frac{1}{\kappa} = -\frac{1}{V_\rho}\left(\frac{\partial V_\rho}{\partial P}\right)_T = \frac{1}{\rho}\left(\frac{\partial \rho}{\partial P}\right)_T$$	
Adiabatic compressibility: (ultrasonic interferometer)	$$\alpha_{\mathrm{ad}} = \frac{1}{\kappa} = \frac{\gamma}{\rho c^2} = \frac{1}{\rho c^2}$$ $$c = \lambda f$$	
Surface tension σ_s:		
a) Force balance for a U-shaped wire frame with a movable side:	$$F = 2b\sigma_s$$	b = breadth of the movable side of the frame
b) Work done to stretch the wire frame by area $\Delta A = 2b\,\Delta x$:	$$W = F\,\Delta x = \sigma_s\,\Delta A$$	Δx = distance moved
c) Excess pressure inside a droplet or air bubble of radius R:	$$\Delta P_{\mathrm{droplet}} = P_i - P_o = \frac{2\sigma_s}{R}$$	P_i and P_o are the pressures inside and outside the droplet or bubble.
d) Excess pressure inside a soap bubble of radius R:	$$\Delta P_{\mathrm{bubble}} = P_i - P_o = \frac{4\sigma_s}{R}$$	
e) Surface energy increase in the droplet:	$$\delta W_{\mathrm{surface}} = \sigma_s dA = \sigma_s d(4\pi R^2) = 8\pi R \sigma_s dR$$	

Capillary rise in a circular tube of constant radius R:	$h = \frac{2\sigma_s}{\rho g R}\cos\phi$	ρ = density of the liquid g = acceleration due to gravity ϕ = contact (or wetting) angle
Reynolds number for internal flow in a circular pipe:	$\text{Re} = \frac{\text{Inertial forces}}{\text{Viscous forces}} = \frac{V_{\text{avg}}D}{\nu} = \frac{\rho V_{\text{avg}}D}{\mu}$	V_{avg} = average flow velocity D = diameter of the pipe
Streamline equation:	$\frac{dr}{V} = \frac{dx}{u} = \frac{dy}{v} = \frac{dz}{w}$	$d\vec{r} = dx\hat{i} + dy\hat{j} + dz\hat{k}$ = infinitesimal arc length
Pathline: (location at time t)	$\vec{x} = \vec{x}_{\text{start}} + \int_{t_{\text{start}}}^{t} \vec{V}\,dt$	$\vec{V} = u\hat{i} + v\hat{j} + w\hat{k}$ = velocity vector
Integral form of the continuity equation:	$\int_{\substack{\text{control}\\ \text{volume}}} \frac{\partial \rho}{\partial t}\,dV_m + \oint_{\substack{\text{control}\\ \text{surface}}} \rho\vec{V}.\hat{n}\,dA = 0$	ρ = density of the fluid at each point in the control volume $\vec{V}$ = velocity of the fluid at each point on the control surface $\hat{n}$ = unit vector outward normal to the control surface dV_m = infinitesimal volume element dA = infinitesimal area element
Continuity equation for a steady flow of an ideal fluid through a tube with varying cross section:	$A_1V_1 = A_2V_2$	V_1 and V_2 are average speeds of the fluid at entrance and exit of the tube. A_1 and A_2 are cross-sectional areas at the entrance end and the exit end.

Fluid Mechanics II

Quantity	Formula	Glossary
Buoyant force:	$F_B = \rho g V$	ρ = density of the fluid g = acceleration due to gravity V = volume of the object P = fluid pressure a = capillary tube radius l = length of capillary tube V = volume of liquid passing through the tube h = height of liquid in capillary tube
Poiseuille's formula for the volume of liquid flowing per second through a cylindrical tube of circular cross section:	$\eta = \frac{\pi a^4}{8l}\left(\frac{P}{V}\right)$ with $P = \rho g h$, $\eta = \frac{\pi \rho g a^4}{8l}\left(\frac{h}{V}\right)$	
Poiseuille's equation in corrected version:	$\eta = \frac{\rho g h \pi a^4}{8V(l+1.64a)} - \frac{V\rho}{8\pi(l+1.64a)}$	
Empirical relation between viscosity and temperature:	$\log \eta = a + \frac{b}{T}$	a and b are constants. T = absolute temperature
Variation of viscosity with temperature according to kinetic theory of gases:	$\eta = \alpha \eta_0 T^{1/2}$	α is a constant η_0 = viscosity at 0° C
Sutherland's modified formula for viscosity:	$\eta = \eta_0 \frac{\alpha T^{1/2}}{1+S/T}$	S = Sutherland's constant
Bernoulli's theorem:	$\frac{P_1}{\rho} + gh_1 + \frac{1}{2}v_1^2 = \frac{P_2}{\rho} + gh_2 + \frac{1}{2}v_2^2 = \text{const.}$ $\frac{P}{\rho} + gh + \frac{1}{2}v^2 = \text{const.}$	P_1 and P_2 are fluid pressures at points 1 and 2. h_1 and h_2 are the heights of the tube from the ground at points 1 and 2. v_1 and v_2 are velocities of the fluid at points 1 and 2.

Venturi meter:	$$\frac{P_1}{\rho g}+h_1+\frac{v_1^2}{2g}=\frac{P_2}{\rho g}+h_2+\frac{v_2^2}{2g}$$ When the tube is horizontal $h_1=h_2$ $$\frac{P_1}{\rho}+\frac{v_1^2}{2}=\frac{P_2}{\rho}+\frac{v_2^2}{2}$$	
Rate of flow using Venturi meter:	$$Q=a_1v_1=a_2v_2$$ $$=a_1a_2\sqrt{\frac{2(P_1-P_2)}{(a_1^2-a_2^2)}}$$ $$=a_1a_2\sqrt{\frac{2\rho gH}{(a_1^2-a_2^2)}}$$	a_1 and a_2 are areas of cross-section of the tube at points 1 and 2. H = rise in fluid level between capillaries attached at points 1 and 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:	$$U(\nu,T)=\frac{8\pi h\nu^3/c^3}{\left[\exp\left(\frac{h\nu}{kT}\right)-1\right]}$$	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:	$v_g = \dfrac{d\omega}{dk}$	
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:	$\Delta x \Delta p_x \geq \frac{h}{4\pi}$ $\Delta E \Delta t \geq \frac{h}{4\pi}$ $\Delta J \Delta \theta \geq \frac{h}{4\pi}$	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:	$\frac{d^2\psi}{dx^2} + \frac{8\pi^2 m}{h^2}(E - V)\psi = 0$	$\psi \equiv \psi(x)$ = 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:	$\frac{d^2\psi}{dx^2} + k^2\psi = 0$ $k^2 = \frac{8m\pi^2 E}{h^2}$	
b) Solution:	$\psi = A\cos(kx) + B\sin(kx)$	
c) Energy eigen values:	$E = \frac{n^2h^2}{8ma^2}$ $n = 1, 2, 3 \ldots$	a = width of the well
d) Normalized wave function:	$\psi_n = \sqrt{\frac{2}{a}}\sin\left(\frac{n\pi}{a}x\right)$	

Principles of Quantum Computation

Quantity	Formula	Glossary
Inner product of two wave functions $\psi(x)$ and $\phi(x)$:	$\langle\psi\|\phi\rangle = \int \psi^* \phi \, dx$ $\langle\phi\|\psi\rangle = \int \phi^* \psi \, dx = \langle\psi\|\phi\rangle^*$	
Wave function as linear combination of basis vectors:	$\|\psi\rangle = a_1\|\phi_1\rangle + a_2\|\phi_2\rangle + \cdots$ $\|\psi\rangle = \sum_{n=1}^{\infty} a_n\|\phi_n\rangle$	$\|\phi_1\rangle, \|\phi_2\rangle, \ldots$ are basis vectors. $a_1, a_2, a_3, \ldots$ are complex coefficients.
Inner product of $\|\psi\rangle$ with itself:	$\langle\psi\|\psi\rangle = \sum_{n=1}^{\infty} \|a_n\|^2$	
Normalization condition:	$\langle\psi\|\psi\rangle = 1$	
Orthogonality condition:	$\langle\psi_1\|\psi_2\rangle = \langle\psi_2\|\psi_1\rangle = 0$	
Condition for orthnormality of basis vectors:	$\langle\phi_1\|\phi_2\rangle = \langle\phi_2\|\phi_1\rangle = 0$ $\langle\phi_1\|\phi_1\rangle = 1$ and $\langle\phi_2\|\phi_2\rangle = 1$ In general $\langle\phi_m\|\phi_n\rangle = \delta_{mn}$	$\delta_{mn} = \begin{cases} 0 & \text{for } m \neq n \\ 1 & \text{for } m = n \end{cases}$
Hermitian matrix **M**:	$\mathbf{M}^\dagger = \mathbf{M}$	$\mathbf{M}^\dagger$ is the conjugate transpose of **M**
Unitary matrix **U**:	$\mathbf{U}^\dagger\mathbf{U} = \mathbf{U}\mathbf{U}^\dagger = \mathbf{I}$	
Pauli's spin matrices:	$\sigma_x = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix}, \sigma_y = \begin{pmatrix} 0 & -i \\ i & 0 \end{pmatrix},$ $\sigma_z = \begin{pmatrix} 1 & 0 \\ 0 & -1 \end{pmatrix}$	$\|0\rangle = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$ and $\|1\rangle = \begin{pmatrix} 0 \\ 1 \end{pmatrix}$
A qubit:	$\|\psi\rangle = \alpha\,\|0\rangle + \beta\,\|1\rangle$	α and β are complex numbers, called the amplitude of the states.
Bloch sphere representation:	$\|\psi\rangle =$ $\cos\frac{\theta}{2}\,\|0\rangle + e^{i\phi}\sin\frac{\theta}{2}\,\|1\rangle$	θ = polar angle ϕ = azimuth angle

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:	$I = nev_dA$	
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:		
a) n-type	$E_{F_n} = \frac{E_C+E_D}{2} - \frac{kT}{2}\ln\frac{N_C}{N_d}$	N_d = donor concentration
b) p-type	$E_{F_p} = \frac{E_V+E_A}{2} + \frac{kT}{2}\ln\frac{N_V}{N_a}$	N_a = acceptor concentration
Law of Mass Action:	$np = n_i^2 = \text{constant}$	

Hall voltage:	$V_H = R_H \dfrac{BI}{t}$	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:	$R_H = \dfrac{-1}{ne}$	
b) For p-type semiconductors:	$R_H = \dfrac{1}{pe}$	

Semiconductor Devices

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

Dielectrics and Transducers

Quantity	Formula	Glossary
Dipole moment of two charges $-q$ and $+q$:	$\mu = (2a)q$	$2a$ distance between the charges
Induced dipole moment:	$\mu = \alpha E$	α = polarizability
Torque on the dipole in an electric field:	$\tau = qE2a\sin\theta = \mu E\sin\theta$	E = applied electric field
Polarization (total dipole moment / unit volume):	$P = \frac{\mu_{\text{total}}}{V}$	V = volume of the dielectric
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
Electronic polarizability:	$\alpha_e = \frac{\epsilon_0(\epsilon_r - 1)}{N}$	α_e = electronic polarizability
Ionic Polarization:	$P_i = N\alpha_i E$	α_i = ionic polarizability
Orientation or dipole Polarization:	$P_o = \frac{N\mu^2 E}{3kT}$	k = Boltzmann constant T = temperature μ = dipole moment
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:	$\mathrm{NA} = \sin\theta_0 = \dfrac{\sqrt{n_1^2 - n_2^2}}{n_0}$	θ_0 = acceptance angle n_0, n_1 and n_2 are the refractive indices of surrounding medium, core and cladding.
Fraction Index Change:	$\Delta = \dfrac{n_1 - n_2}{n_1}$	
Relation between NA and Δ:	$\mathrm{NA} = n_1\sqrt{2\Delta}$	
V-number if surrounding medium is air:	$V = \dfrac{\pi d}{\lambda}\mathrm{NA}$	d = core diameter λ = wavelength of light
Number of modes for step index fiber:	$\approx \dfrac{V^2}{2}$	
Number of modes for graded index fiber:	$\approx \dfrac{V^2}{4}$	
Attenuation co-efficient (loss per unit length):	$\alpha = -\dfrac{10}{L}\log\left(\dfrac{P_{\mathrm{out}}}{P_{\mathrm{in}}}\right)$	P_{out} = output power P_{in} = input power L = length of the optical fiber

Superconductivity

Quantity	Formula	Glossary
Critical current required to destroy the superconductivity:	$I_c = 2\pi R H_c$	R = radius of the wire H_c = critical magnetic field
Minimum magnetic field required to destroy superconductivity at temperature T:	$H_c = H_0\left[1 - \dfrac{T^2}{T_c^2}\right]$	H_0 = minimum magnetic field required at 0 K to destroy superconductivity T_c = transition temperature

Frequency of electromagnetic radiation emitted by a Josephson junction:	$\nu = \frac{qV}{h} = \frac{2eV}{h}$	h = Planck's constant V = voltage applied q = total charge of the pair e = electronic charge

Material Characterization

Quantity	Formula	Glossary
Ultimate tensile strength: (N/mm^2)	$T_u = \frac{\text{Ultimate Load}}{\left(\begin{array}{c}\text{Original area of}\\ \text{cross-section}\end{array}\right)} = \frac{P_u}{A_0}$	P_u = maximum load where necking down occurs A_0 = initial cross sectional area of specimen
Elastic limit: (N/mm^2)	$T_e = \frac{P_e}{A_0}$	P_e = elastic load limit (in N)
Proportional limit: (N/mm^2)	$T_p = \frac{P_p}{A_0}$	P_p = Proportional load limit (in N)
Yield point: (N/mm^2)	$T_s = \frac{P_s}{A_0}$	P_s = load at the yield point
Stiffness: or the modulus of elasticity:	$E = \frac{T}{\epsilon} = \frac{P_p L}{\epsilon A_0}$	L = gauge length
Rupture: Breaking strength	$= \frac{P_f}{A_0}$	P_f = load at failure
The Brinell Hardness Number (BHN):	$\text{BHN} = \frac{P}{A} = \frac{2P}{\pi D(D - \sqrt{D^2 - d^2})}$	P = load (in N) A = area of contact between the ball and the indentation D = diameter of the ball d = diameter of the impression

Complex reflectance ratio measured in ellipsometry:	$$\rho = \frac{R_p}{R_s} = \tan\Psi\, e^{i\Delta}$$	R_S and R_P are the amplitudes of the s and p components of the polarized light $\tan\Psi$ = modulus of amplitude reflection ratio Δ = phase difference between s and p polarized reflected light
Solar cell I-V characteristics curve: Equation for current:	$$I = I_0\left[\exp\left(\frac{qV}{nkT}\right) - 1\right] - I_L$$	I_0 = dark saturation current q = electronic charge V = applied voltage across the terminals of the diode n = ideality factor k = Boltzmann constant T = temperature I_L = light generated current
Bragg's equation for x-ray diffraction:	$$n\lambda = 2d\sin\theta$$	d = interplanar distance in the crystal θ = incident angle λ = wavelength of x-ray beam $n = 1, 2, 3, \ldots$ specifies the order of reflection
Scherrer equation: Crystallite size,	$$D = \frac{K\lambda}{\beta\cos\theta}$$	β = full width at half maximum of peaks measured in radian located at any 2θ in the pattern K = shape factor and is usually taken as about 0.89.

The kinetic energy E_K of the photoelectron ejected in XPS method:	$E_K = h\nu - E_B - \phi$	h = Plank's constant ν = frequency of the x-rays incident E_B = binding energy of electron ϕ = work function
Limit of resolution of a Scanning Electron Microscope (SEM):	$\Delta x = \dfrac{\lambda}{2\mu \sin\theta}$ $\lambda = \dfrac{h}{\sqrt{2meV}}$	$2\mu \sin\theta$ = numerical aperture of the objective $1/\Delta x$ = resolving power of the microscope λ = de Broglie wavelength of electrons m = mass of the electron e = electronic charge V = voltage with which the electron is accelerated

Formulae used in lab

Quantity	**Formula**	**Glossary**
Volume resonator:	$f_x = \sqrt{\dfrac{(f^2V)_{avg}}{V_x}}$	f = frequency of the tuning fork V = volume of the resonating air
Young's modulus of the material of the cantilever:	$q = \dfrac{4mgL^3}{bd^3\delta_{\text{mean}}}$	δ_{mean} = depression for mass m L, b, d = length, breadth and thickness of the cantilever

Rigidity modulus of the wire of a torsional pendulum:	$\eta = \frac{8\pi L}{R^4}\left(\frac{I}{T^2}\right)$	R = radius L = length of the wire I = moment of inertia of the attached rigid body about the axis of rotation
Moment of Inertia: (with rotation axis passing through their centers)		
a) For circular disc with radius R and mass M:	$I_1 = MR^2/2$	axis $\perp$ to disc plane
	$I_2 = MR^2/4$	axis along diameter
b) For rectangular plate with length L, breadth B and mass M:	$I_3 = M(L^2 + B^2)/12$	axis $\perp$ to plate plane
	$I_4 = ML^2/12$	axis $\perp$ to plate length
	$I_5 = MB^2/12$	axis $\perp$ to plate breadth
Thickness of the paper by interference at an air wedge:	$t = \frac{\lambda L}{2\beta}$	λ = wavelength of the light L = air wedge length β = fringe width
Laser diffraction:	$\lambda = \frac{C \sin\theta_n}{n}$ $\theta_n = \tan^{-1}\left(\frac{x_n}{d}\right)$	C = grating constant n = order of diffraction x_n = distance between central and nth maxima d = distance between grating and screen
Numerical Aperture (NA):	$\sin\theta_0 = \frac{W}{\sqrt{(4L^2 + W^2)}}$	L = distance from the optical fiber to screen
Capacitance and dielectric constant:	$C = \frac{\tau}{R}$ and $\epsilon_r = \frac{Cd}{\epsilon_0 A}$	τ = time constant R = resistance in series
Black box:	$R = \frac{V}{I}$ $L = \frac{V}{2\pi f I}$ $C = \frac{I}{2\pi f V}$	f = frequency of the applied AC source

Series LCR:	$X_L = 2\pi f_0 L$ $X_C = \dfrac{1}{2\pi f_0 C}$ $L = \dfrac{1}{4\pi^2 f_0^2 C}$ $Q = f_0/\Delta f$	L = inductance C = capacitance f_0 = resonance frequency
The diode equation: (at temperature T)	$I = I_0\left[\exp\left(\dfrac{eV}{kT}\right) - 1\right]$	e = electronic charge V = voltage across diode, I = current through the diode. I_0 = reverse saturation current
Wavelength of LED:	$\lambda = \dfrac{hc}{eV_K}$	V_K = knee voltage of the LED
Transistor parameters:	$\beta = \left[\dfrac{I_{C_2} - I_{C_1}}{I_{B_2} - I_{B_1}}\right]_{V_{CE}}$ $\alpha = \dfrac{\beta}{\beta + 1}$	I_C = collector current I_B = base current V_{CE} = voltage across collector & emitter
Fermi energy of copper:	$E_F = 1.36 \times 10^{-15}\sqrt{\dfrac{\rho A m}{l}}$ (in J)	ρ = density of copper. A and l are area of cross-section and length of the wire. m = slope of the resistance versus temperature graph.
Linear Least Square Fit formulas:	$m = \dfrac{n\sum xy - \sum x \sum y}{n\sum x^2 - (\sum x)^2}$ $c = \dfrac{\sum y \sum x^2 - \sum x \sum xy}{n\sum x^2 - (\sum x)^2}$	n = number of data points m = slope c = y-intercept
Band gap of a thermister:	$E_g = \dfrac{4.606\,km}{1.6 \times 10^{-19}}$ (in eV)	k = Boltzmann constant m = slope of the log R versus $1/T$ graph

□