PHYSICS SELECTED EQUATIONS

UNITS

SI base units: m meter (lenght) s second (time) kg kilogram (mass) A ampere (current) K kelvin (temperature) cd candela (luminous intensity) mol mole (substance amount)

Derived units: rad radian (angle) Hz herz (frequency) C coloumb (charge) V volt (voltage) Ω ohm (resistance) F farad (capacitance) H henry (inductance) Wb weber (magnetic flux) T tesla (magnetic field) N newton (force) Pa pascal (pressure) J joule (energy) eV electron volt (energy) W watt (power) Bq becquerel (radioactivity) $\not{u}$ unitless

LINEAR MOTION

$\mathbf{Distance: \ x}$ m $\mathbf{Velocity: \ \vec{v}}$ $\frac{m}{s}$ $\mathbf{Speed: \ v}$ $\frac{m}{s}$ $\mathbf{Time: \ t}$ s $\mathbf{Acceleration: \ \vec{a}}$ $\frac{m}{s^2}$ $\mathbf{Momentum: \ \vec{p}}$ Ns $\mathbf{Impulse: \ \vec{J}}$ Ns or $\frac{kg \cdot m}{s}$

$x = x_0 + \int_{t_0}^{t} v \, dt$ m $v = v_0 + \int_{t_0}^{t} a \, dt$ $\frac{m}{s}$ $v = \frac{dx}{dt}$ $\frac{m}{s}$ $a = \frac{dv}{dt} = \frac{d^2x}{dt^2}$ $\frac{m}{s^2}$ $F = ma$ N $\vec{p} = m\vec{v}$ Ns $\vec{J} = \int_{t_0}^{t} \vec{F} \, dt$ Ns

$x = vt$ m $x = x_0 + v_0 t + \frac{1}{2} a t^2$ m $x = x_0 + \frac{1}{2}(v + v_0)t$ m $v = v_0 + at$ $\frac{m}{s}$ $v^2 = {v_0}^2 + 2ax$ $\frac{m^2}{s^2}$ $v_{avg} = \frac{1}{2}(v_i + v_f)$ $\frac{m}{s}$

Projectile: $x(t) = v_0 \cos\vartheta t$ m $y(t) = v_0 \sin\vartheta t - \frac{g}{2} t^2$ m $y(x) = x \tan\vartheta - \frac{g x^2}{2(v_0 \cos\vartheta)^2}$ m $t = \frac{2 v_0 \sin\vartheta}{g}$ s $\vartheta_{t\,max} = 90°$

range: $R = \frac{v_0^2 \cdot \sin 2\vartheta}{g}$ m $\vartheta_{R\,max} = 45°$ height: $h = \frac{v_0^2 \cdot \sin^2\vartheta}{2g}$ m $\vartheta_{h\,max} = 90°$ $\vec{p} = m\vec{v}$ Ns $\vec{p}_i = \vec{p}_f$ $\vec{F} = \frac{d\vec{p}}{dt}$ N $\vec{J} = \Delta\vec{p}$ Ns

$J = F_{avg}\Delta t = m(v_f - v_i)$ Ns inelastic: $m_A v_A + m_B v_B = (m_A + m_B) v_F$ Ns elastic (enrg consrvd): $m_A v_A + m_B v_B = m_A v_A' + m_B v_B'$ Ns

head on: $v_A - v_B = v_B' - v_A'$ $\frac{m}{s}$ $v_A' = \frac{(m_A - m_B) v_A + 2 m_B v_B}{m_A + m_B}$ $\frac{m}{s}$ $v_B' = \frac{(m_B - m_A) v_B + 2 m_A v_A}{m_A + m_B}$ $\frac{m}{s}$ **balist. pend**: $v = \frac{m + M}{m}\sqrt{2gh}$ $\frac{m}{s}$

Rcket trust: $R v_{rel} = Ma$ N $v_f - v_i = v_{rel} \ln\frac{M_i}{M_f}$ $\frac{m}{s}$ (fuel rate: R $\frac{kg}{s}$ exhaust velocity: v_{rel} $\frac{m}{s}$ 1 year = $3.154 \cdot 10^7$ s 1 ft = 0.3048 m)

ANGULAR MOTION

Angle: ϑ rad **Ang. Velocity**: ω $\frac{rad}{s}$ **Ang. Acceleration**: $\alpha = \frac{\Delta\omega}{\Delta t} = \frac{\tau}{I}$ $\frac{rad}{s^2}$ $\vec{\tau} = I\vec{\alpha}$ Nm **Radius**: r m **Arc length**: $s = \vartheta r$ m

Period: $T = \frac{1}{f}$ s **Frequency**: $f = \frac{\omega}{2\pi} = \frac{v}{2\pi r}$ $\frac{1}{s}$ or Hz **Tangential Velocity**: $v = r\omega = \frac{2\pi r}{T}$ $\frac{m}{s}$ $\omega = \frac{\Delta\vartheta}{\Delta t} = \frac{v}{r} = 2\pi f = \frac{2\pi}{T}$ $\frac{rad}{s}$

Acceleration: **tangential**: $a_t = r\alpha = \frac{\Delta v}{\Delta t}$ $\frac{m}{s^2}$ **centripetal**: $a_c = \frac{v^2}{r} = \omega^2 r$ $\frac{m}{s^2}$ $\vec{a} = \vec{a_t} + \vec{a_c}$ $\frac{m}{s^2}$ $a = \sqrt{a_t^2 + a_c^2}$ $\frac{m}{s^2}$

$\vartheta = \omega t$ rad $\vartheta = \vartheta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$ rad $\vartheta = \vartheta_0 + \frac{1}{2}(\omega + \omega_0)t$ rad $\omega = \omega_0 + \alpha t$ $\frac{rad}{s}$ $\omega^2 = {\omega_0}^2 + 2\alpha\vartheta$ $\frac{rad^2}{s^2}$ $\omega_{avg} = \frac{1}{2}(\omega_i + \omega_f)$ $\frac{rad}{s}$

Mom. of Inertia: $I = \sum m_i r_i^2$ $I_{hoop} = mr^2$ $I_{s.shell} = \frac{2mr^2}{3}$ $I_{cylinder} = \frac{mr^2}{2}$ $I_{sphere} = \frac{2mr^2}{5}$ $I_{rod} = \frac{ml^2}{12}$ $I_{rod-end} = \frac{ml^2}{3}$ $kg \cdot m^2$

$I = I_{cm} + md^2$ kgm² **Ang. Momnt.**: $\vec{L} = \vec{r} \times \vec{p} = I\vec{\omega}$ $\frac{kg \cdot m^2}{s}$ **Torque**: $\vec{\tau} = \vec{r} \times \vec{F} = I\vec{\alpha} = \frac{d\vec{L}}{dt}$ Nm $\omega_{precession} = \frac{\tau}{I\omega_0}$ $\frac{rad}{s}$

$K = \frac{1}{2} I\omega^2$ $W = \tau\Delta\theta$ J **Power**: $P = \tau\omega$ W **Cntr. of mass**: $x_{CM} = \frac{\sum x_i m_i}{\sum m_i}$ $y_{CM} = \frac{\sum y_i m_i}{\sum m_i}$ $z_{CM} = \frac{\sum z_i m_i}{\sum m_i}$ m **Kepler**: $\left(\frac{T_A}{T_B}\right)^2 = \left(\frac{r_A}{r_B}\right)^3$

$v_{orb} = \sqrt{\frac{GM}{r}}$ $\frac{m}{s}$ $v_{esc} = \sqrt{\frac{2GM}{r}}$ $\frac{m}{s}$ $T = 2\pi\sqrt{\frac{r^3}{GM}}$ s $g = G\frac{m_e}{r_e^2}$ $\frac{m}{s^2}$ (grav. const: $G = 6.67 \cdot 10^{-11}$ $\frac{Nm^2}{kg^2}$ $g = 9.81$ $\frac{m}{s^2}$ = 32.2 $\frac{ft}{s^2}$)

FORCE

NEWTON: N or $\frac{kg \cdot m}{s^2}$ $F = ma$ $F = \frac{\tau}{r} = \frac{I\alpha}{r} = \frac{Ia}{r^2}$ N $F = \frac{\Delta p}{\Delta t} = m\frac{\Delta v}{\Delta t}$ N (change in momentum) **Weight**: $F_w = mg$ N $F = \frac{P_{power}}{v}$ N

Gravitational: $F_g = m_1 g = G \cdot \frac{m_1 \cdot m_2}{r^2}$ N **Centripetal**: $F_c = mr\omega^2 = m\frac{v^2}{r}$ N **Spring**: $F_s = ks$ N **Friction**: $F_f = \mu F_N$ N

Electric: $\vec{F}_E = k\frac{|q_1||q_2|}{r^2}\hat{r} = q\vec{E}$ N **Magnetic**: $\vec{F}_{on\,q} = q\vec{v} \times \vec{B} = qvB \cdot \sin\vartheta$ N **Drag**: $D = \frac{1}{2} C\rho A v^2$ N (drag coeficient: C $\not{u}$)

Stress: $\sigma = \frac{F}{A}$ $\frac{N}{m^2}$ or Pa **Strain**: $\epsilon = \frac{\Delta L}{L_0}$ $\not{u}$ **Young's Modulus**: $E = \frac{\sigma}{\epsilon} = \frac{F \cdot L_0}{\Delta L \cdot A}$ $\frac{N}{m^2}$ **Shear Modulus**: $S = \frac{\sigma}{\epsilon} = \frac{F \cdot L_0}{\Delta L \cdot A}$ $\frac{N}{m^2}$

Bulk Modulus: $B = \frac{-\Delta p \cdot V_0}{\Delta V}$ $\frac{N}{m^2}$ (friction coeff. μ $\not{u}$ normal force: F_N N spring const.: k $\frac{N}{m}$ 1 lbf = 4.448 N 1 kg = 2.205 lb_m)

ENERGY WORK POWER

JOULE: J or $\frac{kg \cdot m^2}{s^2}$ or Nm $\quad K_{kinetic} = \frac{1}{2}mv^2 = \frac{1}{2}I\omega^2 = \frac{p^2}{2m} \quad U_{spring} = \frac{1}{2}k(\Delta x)^2 \quad U_{potential} = mgh$ J $\quad F = -\frac{dU}{dx}$ N (1 ft · lb = 1.356 J)

Electro magnetic: $U_{C(stored)} = \frac{1}{2}CV^2$ J $\quad U_{L(stored)} = \frac{1}{2}Li^2$ J $\quad U_{E(density)} = \frac{1}{2}\epsilon_0 E^2 \ \frac{J}{m^3} \quad U_{B(density)} = \frac{1}{2\mu_0}B^2 \ \frac{J}{m^3} \quad E_{electric} = Pt$ J

$U_{gravt} = -G\frac{m_1 m_2}{r}$ J $\quad$ WORK: $W = F\Delta x = \tau\Delta\theta = qE\Delta x$ J $\quad W = -\int_{x_i}^{x_f} kx\,dx = \int_{x_i}^{x_f} F\,dx = \int_{\theta_i}^{\theta_f} \tau\,d\theta = \int_{t_i}^{t_f} P\,dt$ J $\quad W = \vec{F} \circ \vec{x} = Fx\cos\vartheta$ J

POWER P: WATT: W or $\frac{J}{s}$ or $\frac{kg \cdot m^2}{s^3} \quad P = Fv = \frac{E}{t} = \frac{Fx}{t} = \tau\omega = Vi$ W $\quad P_{avg} = \frac{\Delta W}{\Delta t}$ W $\quad P_{inst} = \frac{dW}{dt}$ W $\quad P = \vec{F} \circ \vec{v} = Fv\cos\varphi$ W

(1 W = 0.738 $\frac{ft \cdot lb}{s}$; 1 hp = 746 W = 550 $\frac{ft \cdot lb}{s}$; kilowatt hour: 1 kWh = $3.60 \cdot 10^6$ J; 1BTU = 1055 J; 1Cal = 1kcal = 4.184 kJ)

HARMONIC MOTION

Spring: $T = 2\pi\sqrt{\frac{m}{k}}$ s $\quad \omega = \sqrt{\frac{k}{m}} = \frac{2\pi}{T} = 2\pi f \ \frac{rad}{s}$ (spring constant: k $\frac{N}{m}$) Spring energy: $E = \frac{1}{2}mv^2 + \frac{1}{2}ks^2$ J

Position: $x(t) = A\cos(\omega t + \varphi_0)$ m $\quad$ Velocity: $v(t) = \frac{dx}{dt} = -A\omega\sin(\omega t + \varphi_0) \ \frac{m}{s}$ $\quad$ Accel: $a(t) = \frac{dv}{dt} = -A\omega^2\cos(\omega t + \varphi_0) \ \frac{m}{s^2}$

$v_{max} = \omega A \ \frac{m}{s} \quad a_{max} = A\omega^2 \ \frac{m}{s^2} \quad |v(x)| = \sqrt{\frac{k}{m}(A^2 - x^2)} \ \frac{m}{s} \quad a(x) = \frac{k}{m}x \ \frac{m}{s^2}$ Drag force: $D = -b \cdot v$ N (damp coef: b $\frac{Ns}{m}$)

Time constant: $\tau = \frac{m}{b}$ s $\quad$ Damping: $x(t) = Ae^{-bt/2m}\cos(\omega t + \varphi_0)$ m $\quad x(t)_{max} = Ae^{-bt/2m} = Ae^{-t/2\tau}$ m $\quad E = E_0 e^{-\frac{t}{\tau}}$ J

Pendulumm: $T = 2\pi\sqrt{\frac{L}{g}}$ s $\quad$ Physical pendulum: $T = 2\pi\sqrt{\frac{I}{mgL}}$ s (moment of inertia: I kg · m²) $\quad f = \frac{1}{T} = \frac{\omega}{2\pi}$ Hz

WAVES

Velocity: $v = \lambda f \ \frac{m}{s} \quad \frac{f_1}{f_2} = \frac{\lambda_2}{\lambda_1}$ String: $v = \sqrt{\frac{F_T}{\mu}} \ \frac{m}{s} \quad \lambda = \frac{1}{f}\sqrt{\frac{F_T}{\mu}}$ m Linear density: $\mu = \frac{m}{L} \ \frac{kg}{m}$ (wave length: λ m string tens: F_T N)

Longitudinal waves: $v_{rod} = \sqrt{\frac{E}{\rho}} \ \frac{m}{s} \quad v_{liquid\ or\ gas} = \sqrt{\frac{B}{\rho}} \ \frac{m}{s} \quad P_{avg} = \frac{\mu v\omega^2 y_{max}^2}{2}$ W (Young mod: E $\frac{N}{m^2}$ Bulk mod: B $\frac{N}{m^2}$)

Wave equation: $\frac{\partial^2 y}{\partial t^2} = v^2\frac{\partial^2 y}{\partial x^2} \ \frac{m}{s^2}$ Traveling: $y(x,t) = y_m\sin(kx - \omega t + \varphi_0) = y_m\sin\left[2\pi\left(\frac{x}{\lambda} - \frac{t}{T}\right) + \varphi_0\right]$ m $\quad v = \lambda f = \frac{\lambda}{T} = \frac{\omega}{k} \ \frac{m}{s}$

Standing: $y(x,t) = 2y_m\sin(kx) \cdot \cos(\omega t)$ m $\quad \lambda = \frac{2L}{n}$ m $\quad f_{resonance} = n\frac{v}{2L}$ Hz (n = 1,2,3 ...) Wave number: $k = \frac{2\pi}{\lambda} = \frac{\omega}{v} \ \frac{rad}{m}$

Intensity: $I = \frac{P}{A} \ \frac{W}{m^2} \quad \frac{I_1}{I_2} = \frac{r_2^2}{r_1^2}$ Level: $\beta = 10\log\frac{I}{I_o}$ dB $\quad I = I_0 \cdot 10^{\frac{\beta}{10}} \ \frac{W}{m^2}$ $\left(I_o = 10^{-12} \ \frac{W}{m^2}\right)$ Doppler: $f_{\pm} = f_0\left(\frac{v_s \pm v_{object}}{v_s \mp v_{source}}\right)$ Hz

Open pipe: $f_n = n\frac{v_s}{2L}$ Hz $\quad$ Closed pipe: $f_n = n\frac{v_s}{4L}$ Hz $\quad$ Speed of sound: $v_s \approx (331 + 0.6 \cdot {}^\circ C) \ \frac{m}{s} \quad v_s = 343 \ \frac{m}{s}$ (at 20°C)

FLUIDS

Density: $\rho = \frac{m}{V} \ \frac{kg}{m^3}$ $\quad$ Spec. gravity: $SG_o = \frac{\rho_o}{\rho_{water}}$ ~~u~~ $\quad$ Weight: $F_w = \rho gV$ N $\quad p_{hydrost} = p_0 + \rho gh$ Pa $\quad F_{buoyn} = \rho_f V_f g$ N

Pressure: $p = \frac{F}{A} \ \frac{N}{m^2}$ or Pa (1 atm = 101,300 Pa = 760 mm Hg) Pascal: $p_{out} = p_{in}$ or $\frac{F_{out}}{A_{out}} = \frac{F_{in}}{A_{in}} \ \frac{N}{m^2}$ Flow: $J = A_1v_1 = A_2v_2 \ \frac{m^3}{s}$

$J = \frac{\pi r^4\Delta p}{8\eta L} \ \frac{m^3}{s}$ (viscosity: η Pa · s) Continuity: $\rho_1 A_1 v_1 = \rho_2 A_2 v_2 \ \frac{kg}{s}$ $\quad$ Bernoulli: $p_1 + \frac{1}{2}\rho v_1^2 + \rho gh_1 = p_2 + \frac{1}{2}\rho v_2^2 + \rho gh_2 \ \frac{N}{m^2}$

$v = \sqrt{2gh} \ \frac{m}{s}$ (open tank) Drag Force: $D = \frac{1}{2}C\rho Av^2$ N $\quad$ Terminal speed (falling): $v_t = \sqrt{\frac{2F_g}{C\rho A}} \ \frac{m}{s}$ (drag coeficient: C ~~u~~)

OPTICS AND DIFFRACTION

Luminous intensity: $I_v = \frac{\Phi_v}{4\pi}$ cd (candela) **Illuminance:** $M_v = \frac{\Phi_v}{4\pi r^2}$ lx (lux) **Luminous flux:** $\Phi_v = I_v \cdot 4\pi$ lm (lumen)

Spher. mirror or thin lens: $\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$ m^{-1} $d_i = \frac{d_0 f}{d_0 - f}$ m **Magnf:** $M = \frac{h_i}{h_o} = -\frac{d_i}{d_o}$ × (times) **Sphr srfc:** $\frac{n_1}{d_0} + \frac{n_2}{d_i} = \frac{n_2 - n_1}{r}$ m^{-1}

$f_{mirror} = \frac{R}{2}$ m **Lens maker:** $\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ m^{-1} **Lens power:** $P = \frac{1}{f}$ D (**diopter:** D or m^{-1}) **F stop** $= \frac{f}{D_{diam}}$ u

Lenses in contact: $\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$ m^{-1} $M_{lens} = \frac{d_n}{f}$ × (relaxed eye) $M_{lens} = \frac{d_n}{f} + 1$ (eye at near point: $d_n \approx 0.25$ m)

$M_{micrscpe} = M_{ey} M_{ob} = \left(\frac{d_n}{f_e}\right)\left(\frac{l - f_e}{d_o}\right) \approx \frac{d_n l}{f_e f_o}$ $(f_e, f_o \ll l)$ × $M_{telscpe} = -\frac{f_o}{f_e}$ × $l_{tel.} = f_o + f_e$ **Resl lim:** $\vartheta = \frac{1.22\lambda}{D_{diam}}$ rad $w = \frac{2.44\lambda f}{D_{diam}}$ m

Indx of refract: $n = \frac{c}{v_n}$ u $\lambda_n = \frac{v_n}{f} = \frac{c}{nf} = \frac{\lambda_{vac}}{n}$ m $v_n = \frac{c}{n}$ $\frac{m}{s}$ $f = f_{vac} = f_n$ Hz **Film intfr:** $d_{destr} = \left(m - \frac{1}{2}\right)\frac{\lambda}{n}$ $d_{constr} = \frac{m\lambda}{n}$ m

Snell's law: $\frac{\sin\vartheta_{incident}}{\sin\vartheta_{refracted}} = \frac{n_r}{n_i} = \frac{v_i}{v_r}$ $\vartheta_{critical} = \sin^{-1}\frac{n_r}{n_i}$ rad **Wall**$_{glass}$**:** $\frac{d_w}{d_{app}} = \frac{n_w}{n_2}$ **Doppler:** $\lambda_\pm = \lambda_0 \sqrt{\frac{c \pm v}{c \mp v}}$ m $\left(c = 3 \cdot 10^8 \frac{m}{s}\right)$

Single slit: $\sin\vartheta_{dark} = m\frac{\lambda}{a}$ $\sin\vartheta_{bright} = \left(m + \frac{1}{2}\right)\frac{\lambda}{a}$ (slit width: a m) **Double slit:** $\sin\vartheta_{dark} = \left(m + \frac{1}{2}\right)\frac{\lambda}{d}$ $\sin\vartheta_{bright} = m\frac{\lambda}{d}$

Grating: $\sin\vartheta_{bright} = m\frac{\lambda}{d}$ **Circular aperture:** $\sin\vartheta_{1^{st}\,dark\,ring} = \frac{1.22\lambda}{D_{diam}}$ **Interferometer:** $F_{fringe\,\#} = \frac{\Delta L_{mirror\,shift}}{\lambda/2}$ u

Polarization: $I_p = \frac{I_0}{2}$ $I = I_p \cos^2\vartheta$ $\frac{W}{m^2}$ $\tan\vartheta_p = \frac{n_2}{n_1}$ ($m = 0, 1, 2 \ldots$ $\vartheta \approx \sin\vartheta \approx \tan\vartheta$ for $\vartheta < 5°$ slit width or distance: **d** m)

HEAT AND KINETIC THEORY

Temperature: $°F = \frac{9}{5}°C + 32$ $K = °C + 273$ **Ideal gas law:** $pV = nRT = Nk_BT$ J $\frac{p_1V_1}{T_1} = \frac{p_2V_2}{T_2}$ $\frac{J}{K}$ (at S. T. P. **1.0** mol → **22.4** L)

Pressure: $p = \frac{F}{A}$ $\frac{N}{m^2}$ or Pa **Expansions:** linear: $\Delta L = \alpha L_o \Delta T$ m volume: $\Delta V = \beta V_o \Delta T$ m^3 **Moles:** $n = \frac{M}{m_o} = \frac{N}{N_A}$ mol

Density: $\frac{N}{V}$ $\frac{1}{m^3}$ (1 atm = $1.013 \cdot 10^5$ Pa Mass: molar: **M**; molec.: m_o; atomic mass unit: **1u** = $1.66 \cdot 10^{-27}$ kg; #of molecules: **N**)

(Gas const.: **R** = 8.314 $\frac{J}{mol \cdot K}$ = 0.0821 $\frac{L \cdot atm}{mol \cdot K}$; Boltzman const.: $k_B = \frac{R}{N_A} = 1.38 \cdot 10^{-23}$ $\frac{J}{K}$; Avogadro's #: $N_A = 6.02 \cdot 10^{23}$ $\frac{1}{mol}$)

Mean free path: $\lambda = \frac{1}{4\sqrt{2}\left(\frac{N}{V}\right)r^2}$ m $p = \frac{Nm_o{v_{rms}}^2}{3V}$ Pa **Av. Kin. Energy:** $K = \frac{1}{2}m_ov^2 = \frac{3}{2}k_BT$ J $v_{rms} = \sqrt{\frac{3k_BT}{m_o}} = \sqrt{\frac{3RT}{M}}$ $\frac{m}{s}$

(conductvity: **k** $\frac{J}{s \cdot m \cdot K}$; emisivity: $0 \le \epsilon \le 1$ u black body: $\epsilon = 1$; Stefan Boltzmann const.: $\sigma = 5.67 \cdot 10^{-8}$ $\frac{W}{m^2 \cdot K^4}$)

Speed of sound: $v_s = \sqrt{\frac{\gamma RT}{M}}$ $\frac{m}{s}$ (adiabatic indx: γ) **Heat conduct:** $Q = kA\frac{\Delta T}{d}\Delta t$ J **Radiation intsty:** $I = \epsilon\sigma T^4 = \epsilon\sigma(T_{env}^4 - T^4)$ $\frac{W}{m^2}$

$Q_{heating} = mc\Delta T$ J $Q_{phase\,change} = mL$ J (specific heat: **c** $\frac{J}{kg \cdot K}$ latent heat: **L** $\frac{J}{kg}$) $T_f = \frac{m_Ac_AT_A + m_Bc_BT_B}{m_Ac_A + m_Bc_B}$ K or °C

THERMODYNAMICS AND HEAT ENGINES

First Law: $\Delta U = Q - W$ J **Internal energy:** U J **Second Law:** $\Delta S = \frac{\Delta Q}{T}$ $\frac{J}{K}$ **Entropy change:** ΔS $\frac{J}{K} \ge 0$

monatomic gas: $U = \frac{3}{2}nRT$ J $C_V = \frac{3}{2}R$ $C_P = \frac{5}{2}R$ $\frac{J}{mol \cdot K}$ diatomic gas: $U = \frac{3}{2}nRT$ J $C_V = \frac{5}{2}R$ $C_P = \frac{7}{2}R$ $\frac{J}{mol \cdot K}$

elemental solid: $U = 3Nk_BT = 3nRT$ J $C = 3R$ $\frac{J}{mol \cdot K}$ (molar specific heat: **C** $\frac{J}{mol \cdot K}$ at constant vol: C_V at constant pres: C_p)

Isochoric: $\frac{p_i}{T_i} = \frac{p_f}{T_f}$ $W = 0$ $Q = nC_V\Delta T$ $\Delta U = Q$ J **Isothermal:** $p_iV_i = p_fV_f$ $W = nRT\ln\left(\frac{V_f}{V_i}\right) = p_iV_i\ln\left(\frac{V_f}{V_i}\right)$ J $Q = W$ $\Delta U = 0$ J

Isobaric: $\frac{V_i}{T_i} = \frac{V_f}{T_f}$ $W = p\Delta V$ $Q = nC_P\Delta T$ $\Delta U = Q - W$ J **Any:** $\frac{p_iV_i}{T_i} = \frac{p_fV_f}{T_f}$ **W = area under curve** $\Delta U = nC_V\Delta T$ J

Adiabatic: $p_iV_i^\gamma = p_fV_f^\gamma$ or $T_iV_i^{\gamma-1} = T_fV_f^{\gamma-1}$ $W = (p_fV_f - p_iV_i)(1-\gamma) = -nC_V\Delta T$ $Q = 0$ $\Delta U = -W$ J $\gamma_{mon} = 1.67$ $\gamma_{dia} = 1.40$ u

Carnot eng. eff.: $\eta = \frac{W_{out}}{Q_{in}} = 1 - \frac{Q_L}{Q_H}$ $\eta_{max} = 1 - \frac{T_L}{T_H}$ u $COP_{refrg} = \frac{Q_L}{W_{in}} = \frac{Q_L}{Q_H - Q_L}$ $COP_{ref.max} = \frac{T_L}{T_H - T_L}$ $COP_{heat\,pump} = \frac{Q_H}{W_{in}}$ u

ELECTRICITY

CHARGE: $\mathbf{q}_{\text{particle}}$ $\mathbf{Q}_{\text{total}}$ C (coulomb: C) FIELD: $\vec{E} = k\frac{q}{r^2}\hat{r} = \frac{\vec{F}}{q} = \frac{V}{r}\hat{r}$ $\vec{E}_s = -\frac{\partial V}{\partial s}\frac{N}{C}$ or $\frac{V}{m}$ Force: $\vec{F} = k\frac{|q_1||q_2|}{r^2}\hat{r} = q\vec{E} = \frac{qV}{r}\hat{r}$ N

POTENTIAL volt: $V = k\frac{q}{r} = Er$ V or $\frac{J}{C}$ $V = \int_{s_i}^{s_f}\vec{E}\circ d\vec{s}$ V Energy: $U = k\frac{q_1 q_2}{r} = qV$ J $W = qEd$ J Acceleration: $\vec{a} = \frac{q\vec{E}}{m}\ \frac{m}{s^2}$

CAPACITANCE farad: $C = \frac{Q}{V}$ F or $\frac{C}{V}$ $C_{\text{parallel}} = \epsilon_0\frac{A}{d}$ F $C_{\text{cylindrical}} = \frac{L}{2k\ln(b/a)}$ F $C_{\text{spherical}} = \frac{ab}{k(b-a)}$ F $C_{\text{sphere}} = \frac{R}{k}$ F

CURRENT ampere: $i = \frac{dQ}{dt} = C\frac{dV}{dt}$ A or $\frac{C}{s}$ $\left(\text{permittivity: } \epsilon_0 = 8.85\cdot 10^{-12}\frac{C^2}{Nm^2} \text{ or } \frac{F}{m} \text{ or } \frac{s}{\Omega m};\ k = \frac{1}{4\pi\epsilon_0} = 9.0\cdot 10^9\ \frac{Nm^2}{C^2}\right)$

DIPOLE moment: $\vec{p} = q\vec{d}$ Cm torque: $\vec{\tau} = \vec{p}\times\vec{E}$ Nm $U = -\vec{p}\cdot\vec{E}$ J Charge density: $\lambda = \frac{Q}{l}\ \frac{C}{m}$ $\sigma = \frac{Q}{A}\ \frac{C}{m^2}$ $\rho = \frac{Q}{V}\ \frac{C}{m^3}$

$E_{\text{capacitor}} = \frac{V}{d} = \frac{Q}{\epsilon_0 A} = \frac{\sigma}{\epsilon_0}$ $\vec{E}_{\text{disk}} = \frac{\sigma}{2\epsilon_0}\left(1 - \frac{z}{\sqrt{z^2+R^2}}\right)$ $\vec{E}_{\perp\text{ nc plane}} = \frac{\sigma}{2\epsilon_0}$ $\vec{E}_{\perp\text{ cond plane}} = \frac{\sigma}{\epsilon_0}$ $\vec{E}_{\perp\infty\text{ line}} = k\frac{2\lambda}{r}$ $\vec{E}_{\text{wire}} = \frac{\Delta V_{\text{wire}}}{l}\ \frac{V}{m}$

$\vec{E}_{\text{ring}} = k\frac{zQ}{(z^2+R^2)^{3/2}}$ $\vec{E}_{\text{in sphere}} = k\frac{Qr}{R^3}$ $\vec{E}_{\perp\text{ dipole midle}} = k\frac{\vec{p}}{r^3}$ $\vec{E}_{\text{dipole axis}} = k\frac{2\vec{p}}{r^3}\ \frac{V}{m}$ $V_{\text{dipole}} = k\frac{p\cos\vartheta}{r^2}$ V $U_{E(\text{density})} = \frac{1}{2}\epsilon_0 E^2\ \frac{J}{m^3}$

Gauss: $Q_{\text{enclosed}} = \epsilon_0\Phi_{E\text{ closed surf}}$ C FLUX: $\Phi_E = \vec{E}\circ\vec{A}_{(\text{area})} = \oint\vec{E}\circ d\vec{A} = \frac{Q_{\text{enclosed}}}{\epsilon_0}\ \frac{Nm^2}{C}$ or Vm $U_{C(\text{stored})} = \frac{1}{2}CV^2 = \frac{Q^2}{2C} = \frac{1}{2}QV$ J

$i_{\text{displ}} = \epsilon_0\frac{d\Phi_e}{dt} = C\frac{dV}{dt}$ A e_{current}: $i_e = n_e A v_d\ \frac{(\#\text{ of e})}{s}$ $e_{\text{ density}}$: $n_e\ \frac{(\#\text{ of e})}{m^3}$ $i = e i_e$ A Drift speed: $v_d = \frac{e\tau}{m}E = \frac{i}{n_e e A}\ \frac{m}{s}$

(collisionn time: τ s) Current density: $\vec{J} = n_e e\vec{v}_d = \frac{i}{A} = \sigma_c E\ \frac{A}{m^2}$ $i = \int\vec{J}\circ d\vec{A}$ A $E = \rho J\ \frac{V}{m}$ Conductivity: $\sigma_c = \frac{n_e e^2\tau}{m_e} = \frac{1}{\rho}\ \frac{1}{\Omega m}$

(electron: $e_{\text{charge}} = 1.60\cdot 10^{-19}$ C electron volt: 1.0 eV $= 1.6022\cdot 10^{-19}$ J $e_{\text{mass}} = 9.11\cdot 10^{-31}$ kg; proton: $p_{\text{mass}} = 1.67\cdot 10^{-27}$ kg)

MAGNETISM

FIELD: $\vec{B} = \frac{\mu_0 q}{4\pi r^2}\vec{v}\times\hat{r}$ $d\vec{B} = \frac{\mu_0}{4\pi}\frac{i d\vec{s}\times\hat{r}}{r^2}$ $\vec{B}_{\text{wire}} = \frac{\mu_0 i}{2\pi r}$ $\vec{B}_{\text{dipole}} = \frac{\mu_0\vec{\mu}}{2\pi z^3}$ $\vec{B}_{\text{toroid}} = \frac{\mu_0 iN}{2\pi r}$ T $\left(\text{permeability: } \mu_0 = 4\pi\cdot 10^{-7}\ \frac{Tm}{A}\right)$

$\vec{B}_{\text{arc}} = \frac{\mu_0 i\varphi}{4\pi r}$ $\vec{B}_{\text{coil cntr}} = \frac{\mu_0 iN}{2r}$ $\vec{B}_{\text{solenoid}} = \frac{\mu_0 iN}{l}$ T (N: turns) FORCE: $\vec{F} = q\vec{v}\times\vec{B} = qvB\sin\vartheta$ $\vec{F}_{\text{wire}} = i\vec{l}\times\vec{B}$ $F_{2\text{ wirs}} = \frac{\mu_0 i_1 i_2 l}{2\pi r}$ N

$F_{\text{centrp}} = qv_\perp B = ma_c = m\frac{v_\perp^2}{r}$ N $\omega = \frac{qB}{m}\ \frac{rad}{s}$ $T = \frac{2\pi m}{qB}$ s $r_{\text{orbit}} = \frac{mv_\perp}{qB}$ m $d_{\text{pitch}} = v_\parallel T$ m Ampere law: $\oint_C\vec{B}\circ d\vec{l} = \mu_0 i$ Tm

DIPOLE moment: $\vec{\mu} = Ni\vec{A}$ Am^2 Torque: $\vec{\tau} = \vec{\mu}\times\vec{B}$ Nm $\vec{\tau}_{\text{generator}} = \frac{\omega}{R}(NBA\sin\omega t)^2$ Nm Momentum: $p = mv = qBr$ Ns

FLUX: $\Phi_B = \int\vec{B}\circ d\vec{A}$ Wb or $\frac{J}{A}$ emf: $\mathcal{E} = \oint\vec{E}\circ d\vec{s} = \frac{d\Phi_B}{dt}$ $\mathcal{E}_{\text{self}} = -L\frac{di}{dt}$ $\mathcal{E}_{\text{wire}} = vlB$ $\mathcal{E}_{\text{coil}} = N\frac{d\Phi_B}{dt}$ $\mathcal{E}_{\text{generator}} = NB\omega A\sin\omega t$ V

INDUCTANCE: $L = \frac{N\Phi_B}{i}$ H or $\frac{Vs}{A}$ or sΩ $L_{\text{solenoid}} = \frac{\mu_0 N^2 A}{l}$ H $E_{\text{inside solenoid}} = \frac{r}{2}\frac{dB}{dt}\ \frac{V}{m}$ Energy: $U = -\vec{\mu}\circ\vec{B}$ $U_{L(\text{stored})} = \frac{1}{2}Li^2$ J

$U_{B(\text{density})} = \frac{1}{2\mu_0}B^2\ \frac{J}{m^3}$ $f_{\text{cyclotron}} = \frac{qB}{2\pi m}$ Hz $v_{\text{linear}} = \frac{E}{B}\ \frac{m}{s}$ $\Delta V_{\text{Hall}} = \frac{iB}{dne}$ V (Hall Effect: thickness: d m #of charges denst: n $\frac{1}{m^3}$)

ELECTRIC CIRCUITS

Ohm's law: $i = \frac{V}{R}$ A Power: $P = Vi = i^2R = \frac{V^2}{R}$ W Resistance OHM: $R = \rho\frac{l}{A}\Omega$ Resistivity: $\rho = \frac{1}{\sigma_c} = \frac{E}{J}$ $\Delta\rho = \rho_0\alpha(T - T_0)$ Ωm

$R_{\text{series}} = \sum_{k=1}^{n}R_k$ $R_{\text{parallel}} = \left(\sum_{k=1}^{n}\frac{1}{R_k}\right)^{-1}$ Ω $C_{\text{series}} = \left(\sum_{k=1}^{n}\frac{1}{C_k}\right)^{-1}$ $C_{\text{parallel}} = \sum_{k=1}^{n}C_k$ F $L_{\text{series}} = \sum_{k=1}^{n}L_k$ $L_{\text{parallel}} = \left(\sum_{k=1}^{n}\frac{1}{L_k}\right)^{-1}$ H

$\Delta R = \alpha R_0\Delta T$ Ω $\left(\text{temp. coef.: } \alpha\ \frac{1}{K}\right)$ RC circuit: $i = i_0 e^{\frac{-t}{RC}}$ A $V_C = V_0\left(1 - e^{\frac{-t}{RC}}\right)$ V RL circuit: $i = i_0\left(1 - e^{\frac{-tR}{L}}\right)$ A $V_L = V_0 e^{\frac{-tR}{L}}$ V

LC circuit: $i = i_{\max}\sin\omega t$ $i_{\max} = \omega Q$ A LC $_{\text{oscill}}$: $\omega = \frac{1}{\sqrt{LC}} = 2\pi f\ \frac{rad}{s}$ RLC: $q = Qe^{\frac{-Rt}{2L}}\cos(\omega' t - \varphi)$ C $\omega' = \sqrt{\omega^2 - (R/2L)^2}\ \frac{rad}{s}$

$U_E = \frac{q^2}{2C}$ J AC: $V = V_{\max}\sin\omega t$ V $V_{\text{rms}} = \frac{V}{\sqrt{2}}$ V $i_{\text{rms}} = \frac{I}{\sqrt{2}}$ A $P_{\text{peak}} = 2\bar{P}$ W $\bar{P} = i_{\text{rms}}^2 R = \frac{V_{\text{rms}}^2}{R} = V_{\text{rms}}\,i_{\text{rms}}$ W

Reactance: $X_C = \frac{1}{\omega C} = \frac{1}{2\pi fC}$ Ω $X_L = \omega L = 2\pi fL$ Ω Impedance: $Z = \sqrt{R^2 + (X_L - X_C)^2}$ Ω Phase: $\varphi = \tan^{-1}\frac{X_L - X_C}{R}$ rad

$\bar{P} = i_{\text{rms}}V_{\text{rms}}\cos\varphi = \frac{V_{\text{rms}}^2}{Z}\cos\varphi = i_{\text{rms}}^2 R$ W Resonance: $\omega_{\text{res}} = \frac{1}{\sqrt{LC}}\ \frac{rad}{s}$ or $f_{\text{res}} = \frac{1}{2\pi\sqrt{LC}}$ Hz $\omega_{\text{crossover}} = \frac{1}{RC}\ \frac{rad}{s}$

MAXWELL EQUATIONS AND ELECTROMAGNETIC WAVES

$\textbf{Gauss}_{(\text{electric fields})}$: $\Phi_E = \oint_S \vec{E} \circ d\vec{A} = \frac{Q_{encl}}{\epsilon_0}$ Vm $\vec{\nabla} \circ \vec{E} = \frac{\rho}{\epsilon_0}$ $\frac{N}{C}$ $\textbf{Gauss}_{(\text{magnetic fields})}$: $\Phi_B = \oint_S \vec{B} \circ d\vec{A} = 0$ Wb $\vec{\nabla} \circ \vec{B} = 0$

Faraday: $\mathcal{E} = \oint_C \vec{E} \circ d\vec{s} = -\frac{d\Phi_B}{dt}$ V $\vec{\nabla} \times \vec{E} = -\frac{\partial \vec{B}}{\partial t}$ $\frac{T}{s}$ **Amper − Max.:** $\oint_C \vec{B} \circ d\vec{s} = \mu_0 i + \epsilon_0 \mu_0 \frac{d\Phi_E}{dt}$ Tm $\vec{\nabla} \times \vec{B} = \mu_0 \vec{J} + \epsilon_0 \mu_0 \frac{\partial \vec{E}}{\partial t}$ $\frac{T}{m}$

Electromagnetic waves: $E = E_0 \cos(\omega t - kx)$ $\frac{V}{m}$ $B = B_0 \cos(\omega t - kx)$ T $k = \frac{2\pi}{\lambda}$ $\frac{rad}{m}$ $\omega = ck$ $\frac{rad}{s}$ $c = \frac{E_0}{B_0} = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$ $\frac{m}{s}$

Wave equations: $\nabla^2 \vec{E} = \epsilon_0 \mu_0 \frac{\partial^2 \vec{E}}{\partial t^2}$ $\frac{V}{m^3}$ $\nabla^2 \vec{B} = \mu_0 \epsilon_0 \frac{\partial^2 \vec{B}}{\partial t^2}$ $\frac{T}{m^2}$ $c = \lambda f = \frac{1}{\sqrt{\epsilon_0 \mu_0}}$ $\frac{m}{s}$ **permittivity:** ϵ_0 $\frac{s}{\Omega m}$ **permeability:** μ_0 $\frac{\Omega s}{m}$

Poynting: $\vec{S} = \frac{1}{\mu_0} \vec{E} \times \vec{B}$ $\frac{W}{m^2}$ **Intensity:** $I = c\epsilon_0 E^2 = \frac{c}{\mu_0} B^2 = \frac{EB}{\mu_0} = \frac{P}{4\pi r^2}$ $\frac{W}{m^2}$ **Power:** $P = IA$ W $\left(E_{rms} = \frac{E_{max}}{\sqrt{2}} \ldots\right)$

Radiation pressure: $p_{absor} = \frac{F}{A} = \frac{\bar{I}}{c}$ $\frac{N}{m^2}$ $p_{reflc} = \frac{2\bar{I}}{c}$ $\frac{N}{m^2}$ $F = pA = \frac{P_{(power)}}{c}$ N **Polarized:** $I_{pol} = \frac{I_0}{2}$ $I_{2nd\ pol} = I_{pol} \cos^2 \vartheta$ $\frac{W}{m^2}$

Galilean field transforms: $\vec{E}_B = \vec{E}_A + \vec{v}_{BA} \times \vec{B}_A$ $\frac{V}{m}$ $\vec{B}_B = \vec{B}_A - \frac{1}{c^2} \vec{v}_{BA} \times \vec{E}_A$ T **Lorentz force:** $\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$ N

RELATIVITY

Lorentz tranformations: $\gamma = \frac{1}{\sqrt{1 - v^2/c^2}}$ $\not{u}$ $\beta = \frac{v}{c}$ $\not{u}$ $\beta^2 = 1 - \frac{1}{\gamma^2}$ $\not{u}$ **Momentum:** $\vec{p} = \gamma m \vec{v}$ $\frac{kg \cdot m}{s}$ or $\frac{eV}{c}$

$x' = \gamma(x - vt)$ m $t' = \gamma\left(t - \frac{vx}{c^2}\right)$ s $x = \gamma(x' + vt')$ m $t = \gamma\left(t' + \frac{vx'}{c^2}\right)$ s **Doppler:** $f_\pm = f_0 \sqrt{\frac{c \pm v}{c \mp v}}$ Hz $\lambda_\pm = \lambda_0 \sqrt{\frac{c \mp v}{c \pm v}}$ m

Time dilation: $\Delta t = \gamma \Delta t_0'$ s **Length contraction:** $\Delta L = \frac{\Delta L_0'}{\gamma}$ m **Spacetime interval:** $\Delta s^2 = \Delta x^2 - c^2 \Delta t^2$ m^2 $\Delta s^2 = \Delta s'^2$

$u_x = \frac{u_x' + v}{1 + \frac{u_x' v}{c^2}}$ $u_y = \frac{u_y'}{\gamma\left[1 + \frac{u_y' v}{c^2}\right]}$ $u_z = \frac{u_z'}{\gamma\left[1 + \frac{u_z' v}{c^2}\right]}$ $u_x' = \frac{u_x - v}{1 - \frac{u_x v}{c^2}}$ $u_y' = \frac{u_y}{\frac{1}{\gamma} - \frac{u_y v}{c^2}}$ $u_z' = \frac{u_z}{\frac{1}{\gamma} - \frac{u_z v}{c^2}}$ $\frac{m}{s}$

Energy: $E = \gamma mc^2 = E_0 + E_k = mc^2 + (\gamma - 1)mc^2$ J $E_0 = mc^2$ J $E_k = (\gamma - 1)mc^2$ J $E^2 = p^2c^2 + m^2c^4$ J^2 $E \gg m_0 c^2$: $E_k = pc$ J

(proper (in it's own frame): time: Δt_0, length: ΔL_0; frame velocity: **v** particle velocity: **u** Light year: 1 ly $= 9.46 \cdot 10^{15}$ m)

QUANTUM MECHANICS

(Planck's const: $h = 6.63 \cdot 10^{-34}$ Js $= 4.14 \cdot 10^{-15}$ eVs $\hbar = h/2\pi = 1.06 \cdot 10^{-34}$ Js $= 6.58 \cdot 10^{-16}$ eVs $\lambda_{visible\ light} \cong$ 400 to 700 nm)

(electron: $e_{mass} = 9.11 \cdot 10^{-31}$ kg $= 0.511$ $\frac{MeV}{c^2}$ proton: $p_{mass} = 1.67 \cdot 10^{-27}$ kg $= 938$ $\frac{MeV}{c^2}$ $1u = 1.661 \cdot 10^{-27}$ kg $= 931.5$ $\frac{MeV}{c^2}$)

Black body: $\lambda_{peak} T = 2.9 \cdot 10^{-3}$ mK **Planck:** $I_{per\ \lambda} = \frac{2\pi c^2 h}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1}$ $\frac{W}{m^3}$ $\lambda_{v \ll c} = \frac{h}{mv} = \frac{h}{p} = \frac{h}{\sqrt{2mE_K}}$ m $E_K = eV$ J

Photo elect. efect: $hf = E_k + W_0$ J $\lambda = \frac{hc}{E_n - E_{n'}}$ m $E_n = -13.6 \frac{Z^2}{n^2}$ eV (E_n: Bohr energy levels; **Z**: atomic #)

Charge to mass: $\frac{q}{m} = \frac{E}{B^2 r}$ $\frac{C}{kg}$ $v_{straight} = \frac{E}{B}$ $\frac{m}{s}$ $E_{phot} = hf = \frac{hc}{\lambda} = pc$ J $p_{phot\ momentm} = \frac{h}{\lambda} = \frac{E_{phot}}{c}$ Ns $E_{phot} \cdot \lambda = 1240$ eV · nm

Compton: $\lambda' = \lambda + \frac{h}{m_e c}(1 - \cos\phi)$ m $\lambda_{Compton} = \frac{h}{m_e c} = 2.43 \cdot 10^{-3}$ nm **Wave funct:** $\psi(x) = A \sin(kx) + B\cos(kx)$

$k = \frac{p}{\hbar} = \frac{2\pi}{\lambda} = \frac{\sqrt{2mE}}{\hbar}$ m^{-1} box: $k = n\frac{\pi}{l}$ m^{-1} $E = n^2 \frac{h^2}{8ml}$ J $\psi_n(x) = \sqrt{\frac{2}{l}} \sin\left(\frac{n\pi}{l} \cdot x\right)$ $m^{-\frac{1}{2}}$ **Broglie:** $\lambda = \frac{h}{p} = \frac{h}{m_0 v} \sqrt{1 - \frac{v^2}{c^2}}$ m

Prob. density: $P(x) = |\psi(x)|^2$ m^{-1} **Probability**$(x_L \le x \le x_R) = \int_{x_L}^{x_R} |\psi(x)|^2 dx$ $\not{u}$ $\int_{-\infty}^{\infty} |\psi(x)|^2 dx = 1$ $\not{u}$ $E_k = \frac{p^2}{2m}$ J

Schrödinger's eq: $E\psi(x) = -\frac{\hbar^2}{2m} \frac{d^2\psi}{dx^2} + U(x)\psi(x)$ $\psi(x)_{penetration} = \psi_{edge} e^{-w/\eta}$ $\eta = \frac{\hbar}{\sqrt{2m(U_0 - E)}}$ m $P_{tunnel} = e^{-2w/\eta}$ $\not{u}$

Heisenberg uncertainty: $\Delta x \Delta p \ge \frac{\hbar}{2}$ Js $\Delta E \Delta t \ge \frac{\hbar}{2}$ Js $\frac{\Delta E}{\Delta f} = h$ Js **Wave packet:** $\Delta f \Delta t \approx 1$ $\not{u}$

NUCLEAR PHYSICS

Decay: $N = N_0 e^{-\lambda t}$ units $T_{\frac{1}{2}} = \frac{\ln 2}{\lambda}$ s $t = T_{\frac{1}{2}} \log_{\frac{1}{2}} \frac{N}{N_0}$ s $N = N_0 \left(\frac{1}{2}\right)^{\frac{t}{T_{\frac{1}{2}}}}$ units **Radioactivity**: $\frac{\Delta N}{\Delta t} = \left(\frac{\Delta N}{\Delta t}\right)_0 e^{-\lambda t}$ Bq $\frac{\Delta N}{\Delta t} = \lambda N$ Bq

$A = \left(\frac{r}{r_0}\right)^3$ ~~u~~ $r = r_0 A^{\frac{1}{3}}$ m (number of decays: **N** Becquerel: Bq or $\frac{\text{decays}}{\text{s}}$ Curie: Ci 1 Ci $= 3.7 \cdot 10^{10}$ Bq atomic mass #: **A** ~~u~~

absorbed radiation dose Gray: Gy or $\frac{\text{J}}{\text{kg}}$ $r_0 = 1.2 \cdot 10^{-15}$ m decay const: λ s^{-1})

SI BASE UNITS

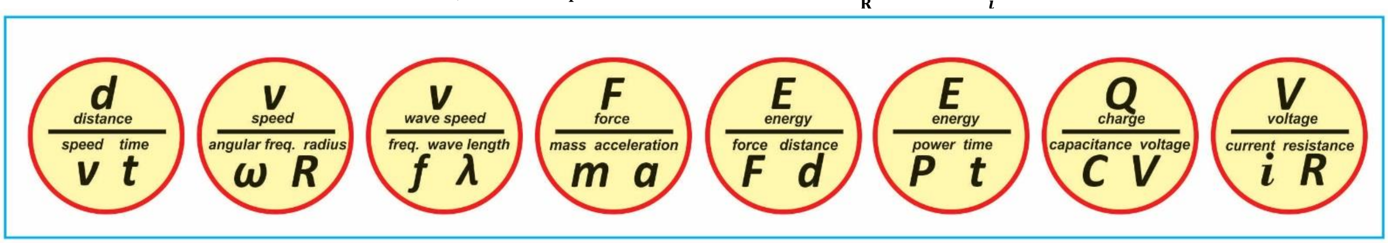
Unit Symbol	Name	Quantity	Symbols
m	meter	length	**x, *l*, h, R, r, s, d,** λ
kg	kilogram	mass	**m, M**
s	second	time	**t, T**
A	ampere	electric current	i, **I**
K	kelvin	temperature	**T**
cd	candela	luminous intensity	**lv**
mol	mole	substance amount	**n**

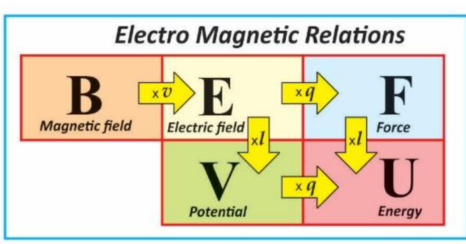
DERIVED UNITS

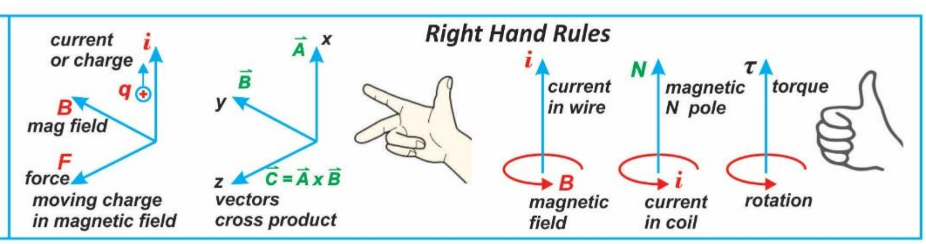
Unit Symbol	Name	Quantity	Symbols	In base units	In other units
Hz	hertz	frequency	**f**	$1/s$	
rad	radian	angle	θ	~~u~~	
N	newton	force	**F**	$kg \cdot m/s^2$	
Pa	pascal	pressure	**p**	$kg/(s^2 m)$	N/m^2
J	joule	energy	**E, U, K, W, eV, Q**	$m^2\,kg/s^2$	$N \cdot m = C \cdot V = W \cdot s$
W	watt	power	**P**	$m^2\,kg/s^3$	$J/s = V \cdot A$
C	coulomb	electric charge	**Q, q**	$A \cdot s$	
V	volt	voltage	**V,** ε,	$m^2\,kg/(s^3 A)$	$W/A = J/C = \Omega \cdot A$
F	farad	capacitance	**C**	$A^2 s^4/(m^2 kg)$	C/V
Ω	ohm	resistance	**R**	$m^2\,kg/(s^3 A^2)$	V/A
Wb	weber	magnetic flux	Φ_B	$m^2\,kg/(s^2 A)$	$T \cdot m^2 = J/A$
T	tesla	magnetic field	**B**	$kg/(s^2 A)$	$Wb/m^2 = N/(A \cdot m)$
H	henry	inductance	**L**	$m^2\,kg/(s^2 A^2)$	$V \cdot s/A = Wb/A$
Bq	becquerel	radioactivity	**Bq**	$1/s$	
lm	lumen	luminous flux	Φ_v	$cd \cdot 4\pi$	
lx	lux	luminous emittance	M_v	cd/m^2	

MNEMONICS

Some basic formulae reminders. Ohms law, for example: $V = i \cdot R$ V $i = \frac{V}{R}$ A $R = \frac{V}{i}$ Ω







LINEAR AND ANGULAR RELATED EQUATIONS		
LINEAR	**ANGULAR**	**QUANTITY**
$\mathbf{x = vt}$ m	$\boldsymbol{\vartheta = \omega t}$ rad	distance, angle
$\mathbf{x = x_0 + v_0 t + \frac{1}{2} a t^2}$ m	$\boldsymbol{\vartheta = \vartheta_0 + \omega_0 t + \frac{1}{2} \alpha t^2}$ rad	
$\mathbf{x = x_0 + \frac{1}{2}(v - v_0) t}$ m	$\boldsymbol{\vartheta = \vartheta_0 + \frac{1}{2}(\omega - \omega_0) t}$ rad	
$\mathbf{v = v_0 + at}$ $\frac{m}{s}$	$\boldsymbol{\omega = \omega_0 + \alpha t}$ $\frac{rad}{s}$	velocity
$\mathbf{v^2 = v_0{}^2 + 2ax}$ $\frac{m^2}{s^2}$	$\boldsymbol{\omega^2 = \omega_0{}^2 + 2\alpha\vartheta}$ $\frac{rad^2}{s^2}$	
$\mathbf{v_{avg} = \frac{1}{2}(v_i + v_f)}$ $\frac{m}{s}$	$\boldsymbol{\omega_{avg} = \frac{1}{2}(\omega_i + \omega_f)}$ $\frac{rad}{s}$	
$\vec{\mathbf{p}} = \mathbf{m}\vec{\mathbf{v}}$ Ns or $\frac{kg \cdot m}{s}$ $\int \mathbf{p dv = E_k}$ J	$\vec{\mathbf{L}} = \mathbf{I}\vec{\boldsymbol{\omega}} = \vec{\mathbf{r}} \times \vec{\mathbf{p}}$ $\frac{kg \cdot m^2}{s}$ $\int \mathbf{L d\boldsymbol{\omega} = E_k}$ J	momentum
$\vec{\mathbf{p}} = \int \vec{\mathbf{F}} \mathbf{dt}$ $\frac{kg \cdot m}{s}$	$\vec{\mathbf{L}} = \int \vec{\boldsymbol{\tau}} \mathbf{dt}$ $\frac{kg \cdot m^2}{s}$	
$\mathbf{p_i = p_f}$: $\mathbf{v_i m_i = v_f m_f}$ $\frac{kg \cdot m}{s}$	$\mathbf{L_i = L_f}$: $\mathbf{I_i \boldsymbol{\omega}_i = I_f \boldsymbol{\omega}_f}$ $\frac{kg \cdot m^2}{s}$	conservation of momentum
$\vec{\mathbf{F}} = \mathbf{m}\vec{\boldsymbol{a}} = \frac{\mathbf{d}\vec{\mathbf{p}}}{\mathbf{dt}}$ N	$\vec{\boldsymbol{\tau}} = \mathbf{I}\vec{\boldsymbol{\alpha}} = \frac{\mathbf{d}\vec{\mathbf{L}}}{\mathbf{dt}} = \vec{\mathbf{r}} \times \vec{\mathbf{F}}$ Nm	force, torque
$\mathbf{E_k = \frac{1}{2} m v^2}$ J $\frac{\mathbf{dE_k}}{\mathbf{dv}} = \mathbf{p}$ $\frac{kg \cdot m}{s}$	$\mathbf{E_k = \frac{1}{2} I \boldsymbol{\omega}^2}$ J $\frac{\mathbf{dE_k}}{\mathbf{d\boldsymbol{\omega}}} = \mathbf{L}$ $\frac{kg \cdot m^2}{s}$	kinetic energy
$\mathbf{W = \int_{x_i}^{x_f} F\, dx}$ J	$\mathbf{W = \int_{\theta_i}^{\theta_f} \boldsymbol{\tau}\, d\boldsymbol{\vartheta}}$ J	work
$\mathbf{P = Fv}$ W or $\frac{J}{s}$	$\mathbf{P = \boldsymbol{\tau\omega}}$ W or $\frac{J}{s}$	power

ELECTRIC AND MAGNETIC RELATED EQUATIONS

ELECTRIC	MAGNETIC	QUANTITY
$\vec{E} = \frac{q}{4\pi\,\epsilon_0 r^2}\hat{r}$ $\frac{N}{C}$ or $\frac{V}{m}$	$d\vec{B} = \frac{\mu_0}{4\pi}\frac{i d\vec{s}\times\hat{r}}{r^2}$ T or $\frac{N}{Am}$ **Biot Savart law**	field
$\vec{F} = q\vec{E}$ $\quad \vec{F} = k\frac{\lvert q_1\rvert\lvert q_2\rvert}{r^2}\hat{r}$ N **Coulomb's law**	$\vec{F} = q\vec{v}\times\vec{B}$ N	force
$U = qV$ J	$U = -\vec{\mu}\circ\vec{B}$ J	energy
$U_{C(stored)} = \frac{1}{2}CV^2 = \frac{Q^2}{2C} = \frac{1}{2}QV$ J	$U_{L(stored)} = \frac{1}{2}Li^2$ J	energy stored
$U_{E(density)} = \frac{1}{2}\epsilon_0 E^2$ $\frac{J}{m^3}$	$U_{B(density)} = \frac{1}{2\mu_0}B^2$ $\frac{J}{m^3}$	energy density
$C = \frac{Q}{V}$ F or $\frac{C}{V}$ or $\frac{s}{\Omega}$	$L = \frac{N\Phi_B}{i}$ H or $\frac{Vs}{A}$ or $s\Omega$	capacitance, inductance
$C_{parallel\ cap} = \epsilon_0\frac{A}{d}$ F	$L_{solenoid} = \mu_0\frac{N^2A}{l}$ H	capacitor, solenoid
$\epsilon_0 = \frac{1.11\cdot 10^{-10}}{4\pi}$ $\frac{C^2}{Vm}$ or $\frac{F}{m}$ or $\frac{s}{m}\Omega^{-1}$	$\mu_0 = 4\pi\cdot 10^{-7}$ $\frac{Tm}{A}$ or $\frac{H}{m}$ or $\frac{s}{m}\Omega$	permittivity, permeability
$\Phi_E = \int \vec{E}\circ d\vec{A}$ $\frac{Nm^2}{C}$ or Vm	$\Phi_B = \int \vec{B}\circ d\vec{A}$ Wb or Tm^2 or $\frac{J}{A}$	flux
$\Phi_E = \oint_S \vec{E}\circ d\vec{A} = \frac{Q_{enclosed}}{\epsilon_0}$ Vm **Gauss' law (E)**	$\Phi_B = \oint_S \vec{B}\circ d\vec{A} = 0$ Wb **Gauss' law (B)**	flux, field through closed surface
$\mathcal{E} = \oint_C \vec{E}\circ d\vec{s} = -\frac{d\Phi_B}{dt}$ V **Faraday's law**	$i = \frac{1}{\mu_0}\oint_C \vec{B}\circ d\vec{s}$ A **Ampere's law**	field in closed loop
$\oint_C \vec{B}\circ d\vec{s} = \mu_0 i + \mu_0\epsilon_0\frac{d\Phi_E}{dt}$ Tm **Ampere – Maxwell law**		field in closed loop
$\vec{p} = q\vec{d}$ Cm	$\vec{\mu} = Ni\vec{A}$ Am^2 (current loop)	dipole moment
$U = -\vec{p}\circ\vec{E}$ J	$U = -\vec{\mu}\circ\vec{B}$ J	dipole potential energy
$\vec{\tau} = \vec{p}\times\vec{E}$ Nm	$\vec{\tau} = \vec{\mu}\times\vec{B}$ Nm	dipole torque
$I = c\epsilon_0 E^2 = \frac{EB}{\mu_0} = \frac{P_{source}}{4\pi r^2}$ $\frac{W}{m^2}$	$I = \frac{c}{\mu_0}B^2 = \frac{EB}{\mu_0} = \frac{P_{source}}{4\pi r^2}$ $\frac{W}{m^2}$	electromagnetic wave intensity
$c^2\nabla^2\vec{E} = \frac{\partial^2\vec{E}}{\partial t^2}$ $\frac{V}{m\cdot s^2}$ $\quad E = E_0\cos(\omega t - kx)$ $\frac{V}{m}$	$c^2\nabla^2\vec{B} = \frac{\partial^2\vec{B}}{\partial t^2}$ $\frac{T}{s^2}$ $\quad B = B_0\cos(\omega t - kx)$ T	electromagnetic wave equations
$c = \frac{1}{\sqrt{\mu_0\epsilon_0}} = \frac{E_0}{B_0}$ $\frac{m}{s}$ $\qquad \mu_0\epsilon_0 = \frac{1}{c^2}$ $\frac{s^2}{m^2}$		speed of light

FUNDAMENTAL CONSTANTS

Speed of light	$c = 2.99792 \cdot 10^{8}$	m/s
Gravitational constant	$G = 6.6742 \cdot 10^{-11}$	$N \cdot m^2/kg^2$
Avogadro's number	$N_A = 6.02214 \cdot 10^{23}$	mol^{-1}
Gas constant	$R = 8.31447$	$J/(mol \cdot K)$
Boltzmann's constant	$k = 1.38065$	J/K
Stefan-Boltzmann's constant	$\sigma = 5.67040 \cdot 10^{-8}$	$W/(m^2 \cdot K^4)$
Permittivity	$\epsilon_0 = 8.85418 \cdot 10^{-12}$	$C^2/(N \cdot m^2)$
Permeability	$\mu_0 = 4\pi \cdot 10^{-7}$	$T \cdot m/A$
Planck's constant	$h = 6.62606 \cdot 10^{-34}$	$J \cdot s$
Electron charge	$e = 1.60217 \cdot 10^{-19}$	C
Electron mass	$m_e = 9.10938 \cdot 10^{-31}$	kg
Proton mass	$m_p = 1.67262 \cdot 10^{-27}$	kg

Astronomical Data						
	Mean orbit	**Period**	**Mass**	**Radius**	**Surface g**	**Orbital v**
	m	years	kg	m	m/s^2	m/s
Sun			1.99E+30	6.96E+08	274.01	
Moon	3.84E+08	27.3 days	7.36E+22	1.74E+06	1.62	1.20E+03
Earth	1.50E+11	1.00	5.98E+24	6.37E+06	9.81	2.99E+04
Mercury	5.79E+10	0.24	3.18E+23	2.43E+06	3.59	4.79E+04
Venus	1.08E+11	0.62	4.88E+24	6.06E+06	8.86	3.50E+04
Mars	2.28E+11	1.88	6.42E+23	3.37E+06	3.77	2.42E+04
Jupiter	7.78E+11	11.90	1.90E+27	6.99E+07	25.94	1.30E+04
Saturn	1.43E+12	29.50	5.68E+26	5.85E+07	11.07	9.66E+03
Uranus	2.87E+12	84.00	8.68E+25	2.33E+07	10.66	6.81E+03
Neptune	4.50E+12	165.00	1.03E+26	2.21E+07	14.07	5.43E+03