All Year 1 eqns

Foundations Equations

Thermodynamics

- $\Delta L = \alpha L_0 \Delta T$ (linear thermal expansion)

ΔL - change in length (m)
α - linear expansion coefficient (K^{-1})
L_0 - initial length (m)
ΔT - change in temperature (K)

- $\Delta V = \beta V_0 \Delta T$ (volume thermal expansion)

ΔV - change in volume (m^3)
β - volume expansion coefficient (K^{-1}) ($\beta = 3\alpha$)
V_0 - initial volume (m^3)

- $Q = nC\Delta\theta$ (molar heat capacity)

Q - heat energy (J)
n - no. of moles (mol)
C - molar heat capacity ($J\,K^{-1}\,mol^{-1}$)
$\Delta\theta$ - change in temperature.

- $Q = mc\Delta\theta$ (specific heat capacity)

m - mass (kg)
c - specific heat capacity ($J\,K^{-1}\,kg^{-1}$)

- $Q = ml$ (specific latent heat)

l - latent heat of fusion / vaporisation ($J\,kg^{-1}$)

- $\frac{dQ}{dt} = -kA\frac{dt}{dx}$ (rate of heat flow)

k - constant of thermal conductivity ($W\,m^{-1}\,K^{-1}$)
A - cross-sectional area (m^2)
$\frac{dt}{dx}$ - temperature gradient ($K\,m^{-1}$)

- $P = e\sigma AT^4$ (Stefan-Boltzmann law of radiation)

P - power (W)
e - surface emissivity (ratio, no units)
σ - Stefan-Boltzmann constant ($5.67\times10^{-8}\,W\,m^{-1}\,K^{-1}$)
A - surface area (m^2)

- $pV = nRT$ or $pV = Nk_BT$ (ideal gas equation)

p = pressure (Pa)
V = volume (m^3)
n = number of moles (mol)
R = molar gas constant ($8.31\ J\ mol^{-1}K^{-1}$)
T = temperature (K)
k_B = Boltzmann constant ($1.38 \times 10^{-23}\ JK^{-1}$)
N = no. of molecules.

- $pV = \frac{1}{3} N m \bar{v}^2$ (Kinetic theory)

m - mass of molecule (kg)
$\bar{v}^2$ - root mean speed squared.

- $E_k = \frac{3}{2} k_B T$ (kinetic energy, average.)

E_k - kinetic energy (J)

- $V_{probable} = \sqrt{\frac{2k_BT}{m}}$ (Most probable speed in a Boltzmann distribution)
- $V_{average} = \sqrt{\frac{8k_BT}{\pi m}}$ (Average speed in a Boltzmann distribution)
- $t_{mean} = \dfrac{V}{4\pi\sqrt{2}\,r^2\,V_{rms}\,N}$ (Average time between collisions)

r - radius of spherical molecule (m)
N - no. of atoms
V_{rms} - root mean squared speed (ms^{-1})

- $\lambda = V_{rms}\,t_{mean}$ (mean 'free' path.)
- $\Delta U = \Delta Q - \Delta W$ (1^{st} law of thermodynamics)

ΔU - change in internal energy (J)
ΔW - work done. (J)

- $W = \int_{V_1}^{V_2} p\, dV$ (Isothermal expansion of ideal gas.)

p = pressure (Pa)

- pV^{γ} = constant (Adiabatic expansion) $\left(\gamma = \frac{C_p}{C_V}\right)$
- $TV^{\gamma-1}$ = constant (Adiabatic expansion)
- $W = nRT \ln\left(\frac{V_2}{V_1}\right)$ (Isothermal expansion, work done.)
- $Q = nC_V\Delta T$ (Isochoric change in heat energy)
- $Q = nC_p\Delta T$ (Isobaric change in heat energy)

- $W = |Q_H| - |Q_c|$ (Work done for a heat engine)

Q_H - heat supplied (J)

Q_c - heat reduced (J)

- $E = \frac{W}{Q_H}$ (Efficiency of an engine.)

$= 1 - \left|\frac{Q_c}{Q_H}\right|$

- $K = \frac{|Q_c|}{W}$ (Performance coefficient for a heat pump.)

- $W = \frac{-1}{(\gamma - 1)}(P_2 V_2 - P_1 V_1) = -nC_v \Delta T$ (work done in an adiabatic expansion)

- $\varepsilon = 1 - \frac{T_C}{T_H}$ (Efficiency of the Carnot cycle).

T_c - temperature of cold reservoir (K)

T_H - temperature of hot reservoir (K)

- $\Delta S = \frac{Q}{T}$ (Entropy change for a reversible process.)

ΔS - change in entropy, (JK^{-1})

- $\Delta S = \int_{\text{state 1}}^{\text{state 2}} \frac{dQ}{T}$ (Entropy change for non-isothermal)

Waves

$u(x,t) = A\cos(kx - \omega t)$ (general waveform, sinusoidal.)

A - amplitude (m)

x - displacement (m)

t - time (s)

ω - angular velocity / frequency ($rad\,s^{-1}$)

k - wavenumber (m^{-1})

- $k = \frac{2\pi}{\lambda}$ (wavenumber)

λ - wavelength (m)

- $\omega = 2\pi f$ (angular velocity)

f - frequency (Hz)

- $c = f\lambda$ (wavespeed equation)

c = wavespeed (ms^{-1})

- $$\frac{\partial^2 u}{\partial t^2} = c^2 \frac{\partial^2 u}{\partial x^2}$$ (wave equation)

c - wavespeed (ms^{-1})

- $$V_g = \frac{d\omega}{dk}$$ (group velocity)

V_g - group velocity (ms^{-1})
ω - angular velocity (rad s^{-1})
k - wavenumber (m^{-1})

- $$c = \frac{\omega}{k}$$ (wavespeed)

ω - angular velocity (rad s^{-1})
k - wave number (m^{-1})

- $$c = \frac{1}{\sqrt{\mu_0 \varepsilon_0}}$$ (speed of light)

μ_0 - permeability of free space
ε_0 - permittivity of free space

- $$\omega(k) = k\sqrt{\frac{B}{\rho}}$$ (dispersion relation)

B - Bulk modulus of air (Pa)
ρ - density of air ($kg\,m^{-3}$)

- $$V_g = \sqrt{\frac{B}{\rho}} = \frac{\omega}{k} = v$$ (group velocity in air)

- V_g - group velocity (ms^{-1})
v - wavespeed (ms^{-1})

- $$\mu \frac{\partial^2 y}{\partial t^2} = T \frac{\partial^2 y}{\partial x^2}$$ (wave equation for mechanical waves)

μ - mass per unit length ($kg\,m^{-1}$)
T - tension (N)

- $$c = \sqrt{\frac{T}{\mu}}$$ (wavespeed of mechanical waves)

- $P = -T \frac{dy}{dx} \cdot \frac{dy}{dt}$ (power transfer of mech. wave.)

T - tension (Pa)

eg: consider a sinusoidal wave, $f(t, x) = A \cos(kx - \omega t)$

$P = TA^2 k\omega \sin^2(kx - \omega t)$

- $k = \omega \sqrt{\frac{\mu}{T}}$ (equating wavespeed equations)

Then, $P = \omega^2 A^2 \sqrt{\mu T} \sin^2(kx - \omega t)$

- $Z = \sqrt{\mu T}$ (impedance)

Z - impedance ($kg\ s^{-1}$)

μ - mass per unit length ($kg\ m^{-1}$)

T - tension (N)

- $P_{average} = \frac{1}{2} \omega^2 A^2 Z$ (average power transmitted)

ω - angular velocity ($rad\ s^{-1}$)

A - amplitude (m)

Z - impedance ($kg\ s^{-1}$)

- Strain $= \frac{\Delta \sigma}{\Delta x}$

- Stress $= \frac{F}{A}$

- Young's modulus $= Y = \frac{\text{Stress}}{\text{strain}} = \frac{F \Delta x}{A \Delta \sigma}$

- $v = \sqrt{\frac{Y}{\rho}}$ (wavespeed of longitudinal elastic waves along a rod.)

Y - young's modulus of rod (Pa)

ρ - density of rod

- $v = \sqrt{\frac{G}{\rho}}$ (wavespeed of a shear wave)

G - shear modulus of rod (Pa)

$p = A k_B \sin(kx - \omega t)$ (pressure of wave in Bulk gas/liquid)

k_B - Boltzmann constant

$v = \sqrt{\frac{B}{\rho}}$ (wavespeed in liquids and gases)

B - Bulk modulus (Pa)
ρ - density ($kgms^{-1}$)

$v_{sound} = \sqrt{\frac{\gamma_p V}{N_m}} = \sqrt{\frac{\gamma k_B T}{m}}$ (speed of sound in ideal gas)

γ - adiabatic index
T - temperature (K)
m = mass of one molecule. (kg)

$v_{sound} = v_{rms} \sqrt{\frac{\gamma}{3}}$ (using ideal gas relations)

v_{rms} - root mean speed squared. (ms^{-1})

$v_p = \sqrt{\frac{B + \frac{4G}{3}}{\rho}}$ (p - wavespeed, compressional waves)

B - Bulk modulus (Pa)

$v_s = \sqrt{\frac{G}{\rho}}$ (s - wavespeed, shear waves)

G - shear modulus (Pa)
ρ - density (kgm^{-3})

$T = \frac{A_t}{A_i} = \frac{2Z_i}{Z_i + Z_t}$ (transmission coefficient)

A_t - amplitude of transmitted wave (m)
A_i - amplitude of incident wave (m)
Z_i - impedance of incident wave ($kg s^{-1}$)
Z_t - impedance of transmitted wave ($kg s^{-1}$)

$R = \frac{A_r}{A_i} = \frac{Z_i - Z_t}{Z_i + Z_t}$ (reflection coefficient)

A_r - amplitude of reflected wave (m)

$Z_{fluid} = \sqrt{\rho B}$ (impedance of a fluid)

ρ - density of fluid ($kg m^{-3}$)
B - bulk modulus

- $\lambda = \frac{2L}{n}$ (wavelength of standing wave of fixed ends)

n - harmonic number (integer)
L - length ~~of~~ between fixed ends (m)

- $c = f\lambda$ (wave equation)

c - wavespeed (ms^{-1})
f - frequency (Hz)
λ - wavelength (m)

- $f' = f\left(\frac{c + u_o}{c + u_s}\right)$ (Doppler effect for sound)

f' - observed frequency (Hz)
f - emitted frequency (Hz)
c - speed of sound (ms^{-1})
u_o - speed of observer (ms^{-1})
u_s - speed of source (ms^{-1})

- $f' = f\sqrt{\frac{c - v}{c + v}}$ (Doppler effect for em. waves)

c - speed of light (ms^{-1})
v - velocity of observer (ms^{-1})

- $I = I_0 \cos^2 \theta$ (Malus's law)

I - intensity (Wm^{-2})
I_0 - initial intensity (Wm^{-2})
θ - angle of polariser (°)

- $I = \frac{1}{2} \varepsilon_0 c E_0^2$ (Intensity of em. wave)

ε_0 - permittivity of free space
c - speed of light (ms^{-1})
E_0 - amplitude (m)

- $\frac{dp}{dt} = \frac{I}{c}$ (light pressure)

I - intensity (Wm^{-2})
c - speed of light (ms^{-1})

$n = \frac{c}{v}$ (refractive index)

n - refractive index (ratio) $(n > 1)$
c - speed of light in vacuum (ms^{-1})
v - speed of light in material (ms^{-1})

$n_i \sin\theta_i = n_t \sin\theta_t$ (Snell's law)

n_i - incident refractive index (ratio)
n_t - transmitted refractive index (ratio)
θ_i - angle of incidence (°)
θ_t - angle of refraction (°)

$T = \frac{4 n_i n_t}{(n_i + n_t)^2}$ (transmission coefficients for refraction)

$R = \frac{(n_i - n_t)^2}{(n_i + n_t)^2}$ (reflection coefficients for refraction)

$\tan\theta_p = \frac{n_t}{n_i}$ (polarization angle)

θ_p - polarization angle (°)

$n\lambda = d\sin\theta$ (constructive interference)

n - integer, peak number
λ - wavelength (m)
d - source separation (m)
θ - angle (°)

$I_{total} = I_0 \cos^2\left(\frac{kd}{2}\sin\theta\right)$ (total intensity)

k - wavenumber (m^{-1})

$I(\theta) = I_0 \left(\frac{\sin\beta}{\beta}\right)^2$ (diffraction from one slit)

$\beta = \frac{ka}{2}\sin\theta$

I_0 - initial intensity (Wm^{-2})
a - slit separation (m)

- $I(\theta) = I_0 \cos^2\left(\frac{kd}{2}\sin\theta\right)\left(\frac{\sin\beta}{\beta}\right)^2$ (diffraction from 2 identical slits)
- $I(\theta) = I_0 \left(\frac{\sin\beta}{\beta}\right)^2 \left(\frac{\sin\left(N\frac{kd}{2}\sin\theta\right)}{\sin\left(\frac{kd}{2}\sin\theta\right)}\right)^2$ (diffraction from N identical slits)

~~4~~ N - number of slits

- $\sin\theta = \frac{1.22\lambda}{D}$ (circular apeture diffraction)

D - diameter of circular apeture (m)

- $f = \frac{1}{2l}\sqrt{\frac{T}{\mu}}$ (first harmonic frequency)

l - length of string (m)
T - tension (N)
μ - mass per unit length ($kg\,m^{-1}$)

- $w = \frac{\lambda D}{s}$ (double-slit formula)

w - fringe spacing (m)
D - distance from screen to slits (m)
s - slit separation (m)

Mechanics equations

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- $\vec{p} = m\vec{v}$ (momentum)

m - mass (kg)
$\vec{v}$ - velocity (ms^{-1})
$\vec{p}$ - momentum ($kg\,ms^{-1}$)

- $\vec{F} = \frac{d\vec{p}}{dt} = m\frac{d\vec{v}}{dt} = m\vec{a}$ (Newtons 2^{nd} law) ← (only holds for constant mass)

$\vec{a}$ - acceleration (ms^{-2})

- $\vec{F}_s \leq \mu_s \vec{N}$ (static friction)

$\vec{F}_s$ - frictional force (N)
$\vec{N}$ - normal reaction force (N)

μ_s - coefficient of static friction

- $F_K = \mu_K N$ (kinetic friction)

F_K - kinetic friction force (N)

μ_K - coefficient of kinetic friction

[In general, $\mu_K < \mu_S$]

- $\vec{F}_{12} = -\dfrac{G m_1 m_2}{|\vec{r}|^2}\hat{r}$ and $|\vec{F}| = \dfrac{G m_1 m_2}{r^2}$ (Newton's law of gravitation)

$\vec{F}_{12}$ - force of 1 on 2 (N)

G - gravitational constant

m_1 - mass 1 (kg)

m_2 - mass 2 (kg)

$\hat{r}$ - unit vector pointing from 1 to 2 (m)

- $\vec{r}_{cm} = \dfrac{\sum_i m_i \vec{r}_i}{\sum_i m_i}$ (position of centre of mass)

$\vec{r}_{cm} = \dfrac{\int \vec{r}\, dm}{\int dm}$ (position of centre of mass of continuous bodies.)

- $\int \vec{r}\, dm = \left[\int x\, dm, \int y\, dm, \int z\, dm \right]$
- $v = u + at$
- $s = ut + \frac{1}{2}at^2$
- $s = vt - \frac{1}{2}at^2$ (SUVAT eqns)
- $v^2 = u^2 + 2as$
- $s = \left(\dfrac{u+v}{2}\right)t$

v - final velocity (ms^{-1})

u - initial velocity (ms^{-1})

s - displacement (m)

a - acceleration (ms^{-2})

t - time (s)

- $v - u = \int_0^t a(t)\,dt$ (time-dependant acceleration)
- $\frac{1}{2}(v^2 - u^2) = \int_0^x a(x)\,dx$ (position-dependant acceleration)
- $\int_u^v \frac{1}{a(v)}\,dv = t$ (velocity-dependant acceleration)
- $T = \frac{1}{2}mv^2$ (kinetic energy)
- $W = \int F\,dx = \Delta T$ (work done)

T - kinetic energy (J)
F - force (N)
W - work done (J)

- $\oint \vec{F} \cdot d\vec{r} = 0$ (work done in a loop)
- $E = T + U$ (conservation of energy)

E - total energy (J)
U - potential energy (J)

- $F = -\frac{dU}{dx}$ (force from potential)
- $\vec{F} = -\frac{\partial u}{\partial x}\hat{i} - \frac{\partial u}{\partial y}\hat{j} - \frac{\partial u}{\partial z}\hat{k} = -\nabla u$ (vector force from potential)
- $u(r) = -\frac{GMm}{r}$ (gravitational potential energy)

G - gravitational constant
M - large mass (kg)
m - small mass (kg)
r - distance between masses (m)

- ~~es~~ $v \geq \sqrt{\frac{2GM}{R}}$ (escape velocity)

M - mass of planet (kg)
R - radius of planet (m)

- $P = \frac{dW}{dt} = \vec{F} \cdot \vec{v}$ (dot product) (Power)

P - power (W)
$\vec{F}$ - force (N)
$\vec{v}$ - velocity (ms^{-1})

- $F = -kx$ (force from spring)

k - spring constant (Nm^{-1})
x - extension (m)

- $\frac{d^2x}{dt^2} + \omega^2 x = 0$ (equation of SHM)
- $\omega^2 = \frac{k}{m}$ (angular velocity)
- $x = A\cos(\omega t) + B\sin(\omega t)$ (solution to SHM eq.)

A and B - constants

- $f = \frac{\omega}{2\pi} = \frac{1}{T}$
- $T = \frac{2\pi}{\omega} = \frac{1}{f}$

(period and frequency relations)

- $x = A'\cos(\omega t + \phi)$ (alternative solution)

A' - amplitude (m)
ϕ - phase angle (rad.)

- $T = 2\pi\sqrt{\frac{m}{k}}$ (period of mass-spring system)
- $U = \frac{1}{2}kx^2$ (potential energy of a spring)
- $U_{av} = \frac{1}{4}kA^2$ (average energy of an oscillating spring)
- $\ddot{x} + \gamma\dot{x} + \omega^2 x = 0$ (damped SHM eq.)
- $\gamma = \frac{b}{m}$ (damping coefficient)

b - damping constant

- $p = -\frac{\gamma}{2} \pm \sqrt{\left(\frac{\gamma}{2}\right)^2 - \omega^2}$ (solution to SHM damped eq.)

- $\gamma < 2\omega$ (light / under-damping)
- $\gamma > 2\omega$ (heavy / over-damping)
- $\gamma = 2\omega$ (critical damping)
- $x = |a| e^{-\gamma t/2} \cos(\omega' t + \phi)$ (light damping solution)
- $\omega' = \sqrt{\omega^2 - \left(\frac{\gamma}{2}\right)^2}$ (reduced angular velocity)

ϕ - phase angle.
a - constant

- $z = a e^{p_1 t} + b e^{p_2 t}$ (over-damped solution)
- $x = \mathrm{Re}(z)$

p_1 and p_2 are solutions of the damped eqn.

- $z = (a + bt) e^{-\gamma t/2}$ (critically - damped solution)
- $x = \mathrm{Re}(z)$

a and b are constants.

- $\ddot{z} + \gamma \dot{z} + \omega_0^2 z = \frac{F_0}{m} e^{i\omega t}$ (forced oscillations)

ω_0 - natural frequency (s^{-1})
ω - applied frequency (s^{-1})
F_0 - force applied (N)

- $a = \dfrac{F_0/m}{(\omega_0^2 - \omega^2) + i\gamma\omega}$ (solution to forced oscillations)
- $|a| = \dfrac{F_0/m}{\sqrt{(\omega_0^2 - \omega^2)^2 + (\gamma\omega)^2}}$ (amplitude modulus)
- $\tan\phi = -\dfrac{\gamma\omega}{\omega_0^2 - \omega^2}$ (phase angle)
- $|a|_0 = \dfrac{F_0}{m\omega_0^2}$ (for $\omega = 0$)
- $\dfrac{d^2\theta}{dt^2} = -\dfrac{g}{L} \sin\theta$

θ - angle from vertical (rad)
g - gravity (ms^{-2})

l - length of string (m)

- $\omega^2 = \frac{g}{l}$ (frequency of pendulum)

- $T = 2\pi\sqrt{\frac{l}{g}}$ (period of pendulum)

- $m\,dv = -v_e\,dm$ (infinitesimal momentum conservation for rockets)
- $v - v_0 = v_e \ln\left(\frac{M_0}{m}\right)$ (rocket eqn.)

V_0 - initial velocity (ms^{-1})
v - final velocity (ms^{-1})
v_e - exhaust velocity (ms^{-1})
M_0 - initial mass (kg)
m - final mass (kg)

- $m\frac{dv}{dt} = -v_e\frac{dm}{dt}$ (rocket thrust)

- $\omega = \frac{v}{r} = \frac{d\theta}{dt}$ (angular velocity)

- $\vec{v} = \vec{\omega} \times \vec{r}$ (angular velocity vector)

$\vec{v}$ - velocity (ms^{-1})
$\vec{r}$ - position vector (m)

- $a = \omega v = \omega^2 r = \frac{v^2}{r}$ (centripetal acceleration)

- $v = \sqrt{\frac{GM_p}{R}}$ (orbital velocity)

v - orbital velocity (ms^{-1})
G - gravitational constant &
M_p - mass of planet/star (kg)
R - orbital radius (m)

- $\omega^2 = \frac{4\pi^2}{P^2} = \frac{GM_p}{R^3}$ (Kepler's 3rd law)

P - orbital period (s)

- $\vec{\tau} = \vec{r} \times \vec{F}$ (torque)

$\vec{\tau}$ - torque (Nm)
$\vec{F}$ - force applied (N)
$\vec{r}$ - position vector (m)

- $M = Fd$ (moments)

M - moment (Nm)

- $\vec{L} = \vec{r} \times \vec{p}$ (angular momentum)

$\vec{L}$ - angular momentum ($kg\,m^2 s^{-1}$)
$\vec{r}$ - position vector (m)
$\vec{p}$ - linear momentum ($kg\,ms^{-1}$)

- $\vec{\tau} = \dfrac{d\vec{L}}{dt}$ (torque + angular momentum relation)

- $I = mr^2$ (moment of inertia)

I - moment of inertia ($kg\,m^2$)

- $L = I\omega$ (angular momentum of particle moving w/ circular motion)
- $T = \frac{1}{2} I \omega^2$ (kinetic energy ")
- $I = \int r^2 \, dm = \int r^2 \rho \, dV$ (moment of inertia for rigid bodies)

r - perpendicular distance from axis to element (m)
ρ - density ($kg\,m^{-3}$)

- $I = MR^2$ (moment of inertia for a thin ring)

M - mass of ring (kg)
R - radius of ring (m)

- $I = \frac{1}{2} MR^2$ (moment of inertia for a circular disc)

M - mass of disc (kg)
R - radius of disc (m)

- $I = \frac{2}{5} MR^2$ (moment of inertia for uniform sphere)

M - mass of sphere (kg)
R - radius of sphere (m)

- $I = \frac{1}{12} ML^2$ (moment of inertia for a thin rod, ⊥ axis through its centre.)

M - mass of rod (kg)
L - length of rod (m)

- $I = \frac{1}{3} ML^2$ (same rod, but ⊥ axis through one end)
- I (any axis) $= I_{cm}(\parallel) + Md^2$ (parallel axis theorem)

$I_{cm}(\parallel)$ = moment of inertia of centre of mass around a parallel axis ($kg\,m^2$)

- $$\omega^2 = \frac{4\pi^2}{P^2} = \frac{1}{1 + (I_{cm}/Md^2)} \left(\frac{g}{d}\right)$$ (compound pendulum)

P - period of oscillation (s)
d - distance from pivot (m)

- $$\frac{d\vec{L}}{dt} = 0$$ (conservation of angular momentum)

(only if no external torque applied)

- $T = \frac{1}{2} M v_{cm}^2 + \frac{1}{2} I \omega^2$ (angular work)

v_{cm} - velocity of centre of mass (ms^{-1})
I - moment of inertia around an axis through centre of mass parallel to ω. (kgm^2)

- $$P = \frac{dW}{dt} = \tau\omega = \vec{\tau} \cdot \vec{\omega}$$ (angular power)

- $$v_{cm} = \frac{m_1 v_1 + m_2 v_2}{m_1 + m_2}$$ (centre of mass velocity)

m_1 - mass of 1st object (kg)
m_2 - mass of 2nd object (kg)
v_1 - velocity of 1st object (ms^{-1})
v_2 - velocity of 2nd object (ms^{-1})

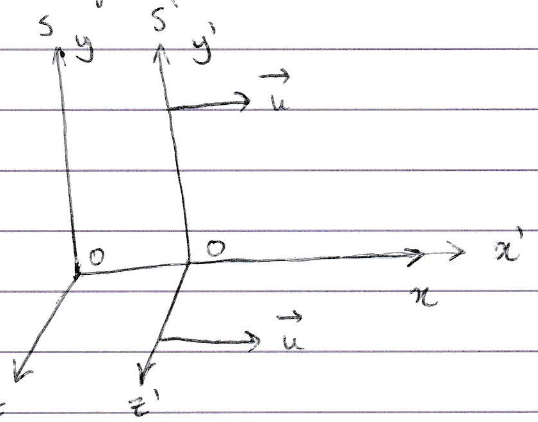
- $$\left.\begin{aligned} u_1 &= v_{cm} + u_1' \\ u_2 &= v_{cm} + u_2' \end{aligned}\right\}$$ (relative velocities)

- $v_1' = v_2' = 0$ (completely inelastic collisions)

- primed velocities are in c.o.m. frame.

Special Relativity

- **Galilean transforms:**



$$x' = x - ut \qquad x = x' + ut$$
$$y' = y \qquad y = y'$$
$$z' = z \qquad z = z'$$
$$t' = t \qquad t = t'$$

for 2 frames, S and S' while S' moves with velocity $u\hat{i}$ ms^{-1}.

- **Lorentz transforms:**

$$x' = \gamma(x - ut) \qquad x = \gamma(x' + ut')$$
$$y' = y \qquad y = y'$$
$$z' = z \qquad z = z'$$
$$t' = \gamma\left(t - \frac{ux}{c^2}\right) \qquad t = \gamma\left(t' + \frac{ux'}{c^2}\right)$$

- $\gamma = \dfrac{1}{\sqrt{1 - \frac{u^2}{c^2}}}$ (Lorentz factor)

Note: to find the inverse transforms, set u to $-u$, and swap $t \to t'$, $x \to x'$, etc.

- $L = \dfrac{L_0}{\gamma}$ (length contraction)

L - observed length (m)
L_0 - rest length (m)
γ - Lorentz factor

- $\Delta t = \gamma \Delta t_0$ (time dilation)

Δt - observed time (s)
Δt_0 - 'proper' time (s)

- $\dfrac{f}{f_0} = \dfrac{1}{\gamma\left(1 + \frac{u}{c}\right)}$ (relativistic doppler shift, moving away)

u - speed of light moving away $(u < c)$ (ms^{-1})
f_0 - 'proper' frequency (Hz)
f - observed frequency (Hz)
γ - Lorentz factor.

$$\frac{f}{f_0} = \frac{1}{\gamma\left(1 - \frac{u}{c}\right)}$$ (relativistic doppler shift, moving towards)

$$\frac{\lambda}{\lambda_0} = \gamma\left(1 \pm \frac{u}{c}\right)$$ (wavelengths instead)

$$\left.\begin{aligned} v &= \frac{v' + u}{1 + \frac{uv'}{c^2}} \\ v' &= \frac{v - u}{1 - \frac{uv}{c^2}} \end{aligned}\right\}$$ (relativistic additions of velocities)

The other components of velocity can be calculated using these eqns.

$m = \gamma m_0$ (relativistic mass)

m_0 - rest mass (kg)

m - observed mass (kg)

$\vec{p} = \gamma m_0 \vec{v}$ (relativistic momentum)

$\vec{v}$ - velocity (ms^{-1})

$\vec{p}$ - relativistic momentum ($kg\,ms^{-1}$)

$\vec{F} = \frac{d\vec{p}}{dt} = \gamma m \vec{a} + \frac{d\gamma}{dt} m_0 \vec{v}$ (relativistic force, uncommon though.)

$E_K = (\gamma - 1) m_0 c^2$ (relativistic kinetic energy)

E_K - kinetic energy (J)

$E = E_0 + E_K = \gamma m_0 c^2 = mc^2$ (total energy)

E - total energy (J)

E_0 - rest mass energy (J)

m_0 - rest mass (kg)

m - observed mass (kg)

$E^2 - p^2 c^2 = m_0^2 c^4 = E_0^2$ (energy-momentum relation, Lorentz invariant)

Particle Physics

PX147

- $\lambda = \frac{h}{p} = \frac{h}{mv}$ (de Broglie wavelength)

λ - de Broglie wavelength (m)
h - Planck's constant
m - mass of particle (kg)
v - velocity of particle (ms^{-1})
p - momentum of particle ($kgms^{-1}$)

- $E = mc^2$ (energy equivalent for mass)
- $E = pc$ (energy equivalent for momentum)
- $E^2 = p^2c^2 + m^2c^4$ (Total energy)
- $M_{initial} \geq \sum_i M_{final}$ (decay)

- $L = L_e + L_\mu + L_\tau$ (Global lepton number)

L_e - electron number
L_μ - muon number
L_τ - tau number

- $F = \alpha_{EM} \frac{q}{r^2}$ (Electromagnetic force)

α_{EM} - intrinsic strength of force
q - charge (C)
r - distance (m)

- $F = \frac{\alpha_s}{r^2} - k$ (Strong force)

α_s - strong force coupling constant
k - constant (~ 1 GeV fm^{-1})

- $F = \alpha_w \frac{e^{-r/R}}{r^2}$ (Weak force)

r - distance
α_w - intrinsic strength

- $R = \frac{\hbar}{M_{W,Z}\, c}$

m - mass of boson (kg)

$\hbar = \frac{h}{2\pi}$ (reduced planck constant)

h - Planck constant

$N(t) = N_0 e^{-\Gamma t} = N_0 e^{-\frac{t}{\tau}}$ (Decay eqn.)

Γ - decay rate (s^{-1})

N_0 - initial number of particles

t - time (s)

τ - decay time of particles (s)

$BR_i = \frac{\Gamma_i}{\Gamma} = \frac{\Gamma_i}{\Sigma_j \Gamma_j}$ (Branching ratio equation)

Γ_i - decay rate for mode i. (s^{-1})

Γ - total decay rate (s^{-1})

BR_i - Branching ratio of i.

$s = (E_1 + E_2)^2 - |p_1 + p_2|^2 c^2$ (Mandelstam - s invariant)

E_1 - energy of 1st particle (J)

E_2 - energy of 2nd particle (J)

p_1 - momentum of 1st particle ($kgms^{-1}$)

p_2 - momentum of 2nd particle ($kgms^{-1}$)

$s_{com} = (E_1 + E_2)^2$ (Mandelstam - s in centre of mass frame)

$s_{fixed} = 2 E_1 m_2 c^2$ (Mandelstam - s in fixed target frame if body 2 is at rest.)

$r = \frac{mv}{qB} = \frac{p}{qB}$ (particles (charged) moving in a magnetic field)

m - mass of particle (kg)

v - linear velocity (ms^{-1})

B - magnitude of magnetic field (T)

q - magnitude of electric charge. (C)

p - momentum ($kgms^{-1}$)

r - radius of path (m)

$t = \frac{\pi m}{qB}$ (time spent in one Dee of cyclotron)

- $r = \frac{\gamma m v}{q B}$ (relativistic radius)

γ - lorentz factor

- $f = \frac{q B}{2\pi \gamma m_0}$ (cyclotron frequency)

- $P(x) = e^{(-\frac{x}{X_0})}$ (radiation probability) (photons)

$P(x)$ - probability of an electron or photon passing unaffected
x - thickness of material (m)
X_0 - radiation length (m)

- $P(x) = e^{(-x/\lambda_1)}$ (radiation probability) (hadrons)

λ_1 - hadronic interaction length (m)

Electricity and Magnetism

PX120

- $\vec{F}_{12} = \frac{q_1 q_2}{4\pi \varepsilon_0} \cdot \frac{\hat{r}}{|\vec{r}|^2}$ (Coulomb's law)

$\vec{F}_{12}$ - force of 1 on 2 (N)
q_1 - charge 1 (C)
q_2 - charge 2 (C)
$\hat{r}$ - unit vector from 1 to 2 (m)
ε_0 - permittivity of free space.

- $\vec{F}_0 = \sum_{i=0}^{N} \vec{F}_{i0} = \frac{q_0}{4\pi\varepsilon_0} \sum_{i=1}^{N} \frac{q_i(\vec{r}_0 - \vec{r}_i)}{|\vec{r}_0 - \vec{r}_i|^3}$ (principle of superposition)

just the vector sum of all forces acting on q_i.

- $\vec{E}(\vec{r}) = \lim_{q_0 \to 0} \frac{\vec{F}_0}{q_0}$ (Electric field relation)

$\vec{E}$ - electric field strength (NC^{-1} or Vm^{-1})
q_0 - test charge (C)
$\vec{F}_0$ - force of charge (N)

- $\vec{F}_0 = q_0 \vec{E}(\vec{r}_0)$ (force on charge in electric field.)

$\vec{r}_0$ - position of charge (m)

- $\vec{E}(r) = \frac{q}{4\pi\varepsilon_0}\frac{\hat{r}}{r^2}$ (electric field around a point charge.)

this is assuming it is at the origin.

- $\lambda = \frac{dq}{dl}$ (linear charge density)

- $\sigma = \frac{dq}{ds}$ (surface charge density)

- $\rho = \frac{dq}{dv}$ (volume charge density)

- $\vec{p} = q\vec{d}$ (electric dipole moment)

$\vec{p}$ - electric dipole moment (Cm)
$\vec{d}$ - distance between two poles, pointing from negative to pos. (m)

- $\vec{\tau} = \vec{p} \times \vec{E}$ (torque from a dipole)

$\vec{\tau}$ - torque about centre of dipole (Nm)

- $u = -\vec{p}\cdot\vec{E}$ (potential energy)

dependant on ϕ, since $u = -\vec{p}\cdot\vec{E} = -pE\cos\phi$

- $\vec{E} \simeq \frac{1}{4\pi\varepsilon_0 r^3}\left[3(\vec{p}\cdot\hat{r})\hat{r} - \vec{p}\right]$ (electric field from a dipole.)

r - position from midpoint of dipole (m)
$\vec{p}$ - dipole moment (Cm)

- $\phi_E = \vec{E}\cdot\vec{S}$ (electric flux)

$\vec{S}$ - surface area (m^2)
ϕ_E - electric flux (Vm)

- $\phi_E = \iint_S \vec{E}\cdot d\vec{s}$ (for an arbitrary surface.)

this is a surface integral.

- $\oiint_S \vec{E}\cdot d\vec{s} = \frac{q_{encl.}}{\varepsilon_0}$ (Gauss's law)

$q_{encl.}$ - enclosed charge by Gaussian surface (C)

- $\vec{E} = 0$ (electric field <u>INSIDE</u> conductors)

for conductors only.

- $W_{A \to B} = \int_a^b \vec{F} \cdot \vec{dl}$ (work done in force field)
- $W_{A \to B} = -\Delta U$ (work done by a conservative force)

U - potential energy (J)

- $\Delta K + \Delta U = 0$ (cons. of energy)

ΔK - kinetic energy. (J)

- $U_{1,2} = \dfrac{q_1 q_2}{4\pi \varepsilon_0 r}$ (potential energy of two charges)

r - distance between charges (J)

- $U_0 = \sum_{i=1}^{N} U_{i0} = \sum_{i=1}^{N} \dfrac{q_i q_0}{4\pi \varepsilon_0 r_{i0}}$ (multiple charge potential)
- $V(\vec{r}) = \lim_{q_0 \to 0} \left(\dfrac{U_{10}}{q_0} \right)$ (electric potential)

$V(\vec{r})$ - electric potential (V)

q_0 - test charge

- $V(\vec{r}) = \dfrac{q}{4\pi \varepsilon_0 |\vec{r} - \vec{r}'|}$ (potential of a point charge)

r' - position of point charge (m)

- $V_{ab} = V_a - V_b = \int_a^b \vec{E} \cdot \vec{dl}$ (electric potential)

line integral here.

- $\vec{E} = -\dfrac{\partial V}{\partial x}\hat{i} - \dfrac{\partial V}{\partial y}\hat{j} - \dfrac{\partial V}{\partial z}\hat{k} = -\vec{\nabla} V$ (potential fields)

$\vec{\nabla}$ - gradient operator.

- $C = \dfrac{Q}{V}$ (capacitor)

C - capacitance (F)
Q - charge (coulomb)
V - voltage / potential difference (V)

- $C = \dfrac{\varepsilon_0 A}{d}$ (parallel plate capacitor)

d - distance between plates (m)

A - surface area of plates (m^2)

- $C = \dfrac{Q}{V_{ab}} = \dfrac{2\pi \varepsilon_0 L}{\ln\left(\frac{R_b}{R_a}\right)}$ (cylindrical capacitor)

R_b - radius from centre to outside plate (m)

R_a - radius from centre to inside plate (m)

L - length of capacitor (m)

- $C = \dfrac{q}{V_{ab}} = \dfrac{\varepsilon_0 4\pi r_a r_b}{r_b - r_a}$ (spherical capacitor)

r_a - radius of 1st plate (m)

r_b - radius of 2nd plate (m)

- $\dfrac{1}{C_{eq.}} = \dfrac{1}{C_1} + \dfrac{1}{C_2}$ (capacitors in series)

- $C_{eq.} = C_1 + C_2$ (capacitors in parallel)

$C_{eq.}$ - equivalent capacitance (F)

- $u = \sum_{i=1}^{n} \frac{1}{2} q_i V_i$ (total potential energy of n charges)

- $u = \frac{1}{2} QV = \frac{1}{2} CV^2 = \frac{1}{2} \frac{Q^2}{C}$ (energy stored in capacitor)

- $u = \dfrac{u'}{V} = \frac{1}{2} \varepsilon_0 E^2$ (energy density for electric field)

u - energy density ($J m^{-3}$)

u' - energy (J)

V - volume (m^3)

E - magnitude of electric field (NC^{-1})

- $\varepsilon_r = \dfrac{C}{C_0} = \dfrac{\varepsilon}{\varepsilon_0}$ (dielectric constant)

C_0 - capacitance separated by vacuum (F)

C - capacitance separated by dielectric (F)

ε - permittivity of material

- $\vec{P}(\vec{r}) = \frac{1}{V} \sum_i \vec{p}_i$ (polarization density)

$\vec{P}(\vec{r})$ - polarization density (Cm^{-2})
V - volume (m^3)
$\vec{p}_i$ - electric dipole moment (Cm)
- $\vec{D} = \varepsilon_0 \vec{E} + \vec{P}$ (electric displacement vector)

$\vec{D}$ - displacement vector (Cm^{-2})
$\vec{E}$ - electric field strength (NC^{-1})
- $\vec{P} = (\varepsilon_r - 1)\varepsilon_0 \vec{E} = \chi_e \varepsilon_0 \vec{E}$ (polarization density round 2.)
- $\chi_e = \varepsilon_r - 1$ (electric susceptibility)
- $I = \frac{dQ}{dt}$ (current)

I - current (A)
Q - charge (C)
t - time (s)
- $\vec{J} = \frac{I}{A}\hat{z} = nq\vec{v}_d$ (current density vector)

$\vec{J}$ - (Am^{-2})
A - cross-sectional area (m^2)
n - number of free charges
$\vec{v}_d$ - drift velocity (ms^{-1})
- $\vec{E} = \rho \vec{J}$ (Ohm's law)
- $\rho = \frac{E}{J}$ (resistivity relation)

ρ - resistivity (Ωm)
- $\sigma = \frac{1}{\rho}$ (conductivity relation)

σ - conductivity ($\Omega^{-1} m^{-1}$)
- $R = \frac{\rho L}{A}$ (resistance for conductor of length L)

A - cross-sectional area (m^2)

- $V = IR$ (Ohm's law)

V - potential difference (V)
R - resistance (Ω)
I - current (A)

- $R_{eq} = R_1 + R_2$ (resistors in series)
- $R_{eq}^{-1} = \frac{1}{R_1} + \frac{1}{R_2}$ (resistors in parallel)

R_{eq} - equivalent resistance (Ω)

- $P = V_{ab} I$ (power dissipated)

V_{ab} - potential difference across circuit element ab.
P - power (W)

- $P = I^2 R = \frac{V_{ab}^2}{R}$ (power across resistor)
- $\frac{P}{V} = \rho J^2$ (power per unit volume)

V - volume (m^3)
ρ - resistivity (Ωm)
J - current density ($A m^{-2}$)

- $V = \mathcal{E} - rI$ (internal resistance and emf.)

$\mathcal{E}$ - electromotive force (N)
r - internal resistance of power supply (Ω)

- $\sum_{i, in} I_i = \sum_{i, out} I_i$ (Kirchoff's Junction rule)

$I_{i(in)}$ - current into a junction (A)
$I_{i(out)}$ - current out of a junction (A)

- $\sum_i \mathcal{E}_i = \sum_j V_j$ (Kirchoff's loop rule)

$\mathcal{E}_i$ - sum of emfs (V)
V_j - sum of voltage drops (V)

- Capacitor charging equations:
- $I = I_0 e^{-\frac{t}{RC}}$
- $Q = Q_0 \left(1 - e^{-\frac{t}{RC}}\right)$
- $V = V_0 \left(1 - e^{-\frac{t}{RC}}\right)$
- Capacitor discharging equations:
- $I = I_0 e^{-\frac{t}{RC}}$
- $V = V_0 e^{-\frac{t}{RC}}$
- $Q = Q_0 e^{-\frac{t}{RC}}$

I_0 - initial current (A)
V_0 - final voltage (V)
Q_0 - final charge (C)
t - time (s)
R - resistance (Ω)
C - capacitance (F)

- $\vec{F} = q\vec{v} \times \vec{B}$ (Lorentz force)

q - charge (C)
$\vec{v}$ - velocity (ms^{-1})
$\vec{B}$ - magnetic field (T)

- $\vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$ (with electric field contribution)

$\vec{E}$ electric field (NC^{-1})

- $\Phi_B = \iint_S \vec{B} \cdot d\vec{S}$ (magnetic flux)

Φ_B - magnetic flux (Wb)
$d\vec{S}$ - surface element (m^2)
Surface integral here.

- $\oiint_S \vec{B} \cdot d\vec{s} = 0$ (Solenoidal condition)
- $R_L = \dfrac{mv}{|q|B}$ (Larmor radius)

R_L - Larmor radius (m)
m - mass of charge (kg)
v - perpendicular velocity (ms^{-1})

- $d\vec{F} = I \, d\vec{l} \times \vec{B}$ (force on section $d\vec{l}$ of wire)

I - current (A)

- $\vec{F} = BIL \, \hat{n}$ (force on moveable crossbar in B)

L - length of crossbar.

- $\vec{\tau} = \vec{\mu} \times \vec{B}$ (torque on rectangular current loop)

$\vec{\mu}$ - magnetic dipole moment (Cm^2s^{-1})
$\vec{\tau}$ - torque (Nm)

- $\vec{\mu} = NIA\hat{n}$ (magnetic dipole moment)

N - number of turns
I - current (A)
A - area of loop (m^2)
$\hat{n}$ - direction perpendicular to plane of loop

- $\vec{B}(\vec{r}, t) = \dfrac{\mu_0}{4\pi} q \dfrac{\vec{v}(t) \times (\vec{r} - \vec{r}\,'(t))}{|\vec{r} - \vec{r}\,'(t)|^3}$ (Biot - Savart law)

μ_0 - permeability of free space
$\vec{v}(t)$ - velocity of charge (ms^{-1})
$\vec{r}(t)$ - position of field strength (m)
$\vec{r}\,'(t)$ - position of charge (m)

- $\dfrac{|F_B|}{|F_E|} = \left(\dfrac{v}{c}\right)^2$ (ratio of forces felt by two moving charges)

$\vec{F}_B$ - magnetic force (N)
$\vec{F}_E$ - electric force (N)
c - speed of light (ms^{-1})

- $\vec{B}(\vec{r}) = \frac{\mu_0}{4\pi} \int I \frac{d\vec{r}' \times (\vec{r} - \vec{r}')}{|\vec{r} - \vec{r}'|^3}$ (Biot - Savart law for a wire)

$\vec{r}'$ - position vector of wire (m)
$\vec{r}$ - position vector of strength of B (m)

- $\vec{B}(\vec{r}) = \frac{\mu_0 I}{2\pi R} \hat{\varphi}$ (magnetic field from straight wire)

R - radial distance from centre of wire (m)
$\hat{\varphi}$ - direction given by right-hand rule

- $\vec{B}(\vec{r}) \approx \frac{\mu_0}{4\pi r^3} [3(\vec{\mu} \cdot \hat{r})\hat{r} - \vec{\mu}]$ (Ideal magnetic dipole field)

$\vec{\mu}$ - magnetic dipole moment ($Cm^2 s^{-1}$)
$\hat{r}$ - direction of position vector (m)

- $\oint_c \vec{B} \cdot d\vec{l} = \mu_0 I_{encl.}$ (Ampère's law)

line integral around a closed loop
$I_{encl.}$ - enclosed current by Ampèrean loop (A)

- $\vec{B}_{outside} = 0$; $\vec{B}_{inside} = \mu_0 n I \hat{z}$ (solenoidal magnetic field)

n - number of turns
I - current (A)

- $\vec{B} = \mu_r \vec{B}_0$ (magnetic field inside materials)

$\vec{B}_0$ - external magnetic field (T)
μ_r - relative permeability

- $\mu_r < 1$ (diamagnetic material)
- $\mu_r > 1$ (paramagnetic material)
- $\mu_r >> 1$ (ferromagnetic material)
- $\mathcal{E} = -N\frac{d\Phi_B}{dt}$ (Faraday's law)

N - number of turns
t - time (s)
Φ_B - magnetic flux (Wb)
$\mathcal{E}$ - emf (V)

- $\mathcal{E} = \oint_{loop} (\vec{v} \times \vec{B}) \cdot d\vec{l}$ (motional emf in closed loop)
- $\mathcal{E} = -\frac{d\Phi_B}{dt} = \oint_c \vec{E} \cdot d\vec{l}$ (stationary emf in closed loop)
- $u = \frac{u'}{V} = \frac{B^2}{2\mu_0}$ (energy density of solenoid)

u - energy density ($J m^{-3}$)
V - volume (m^3)
u' - potential energy (J)

- $I_D = \varepsilon_0 \frac{d\Phi_E}{dt} = \varepsilon_0 \frac{d}{dt} \iint_S \vec{E} \cdot d\vec{S}$ (displacement current)

I_D - displacement current (A)

- $L = \frac{N\Phi_B}{I}$ (self-inductance)

L - self-inductance (H)

- $\mathcal{E} = -L\frac{dI}{dt}$ (emf in an inductor)
- $u = \frac{1}{2}LI^2$ (energy stored by inductor)
- $L_{eq} = L_1 + L_2$ (inductors in series)
- $\frac{1}{L_{eq}} = \frac{1}{L_1} + \frac{1}{L_2}$ (inductors in parallel)

L_{eq} - equivalent inductance (H)

- $\frac{N_s}{N_p} = \frac{V_s}{V_p}$ (Transformer equation)
- $\mathcal{E} = \frac{I_s V_s}{I_p V_p}$ (efficiency of transformer)

N_p - no. of turns of primary coil
N_s - no. of turns of secondary coil
V_p - voltage across primary coil (V)
V_s - voltage across secondary coil (V)
$\mathcal{E}$ - efficiency

- $V(t) = V_0 \cos \omega t = Re\left(V_0 e^{i\omega t}\right)$ (Alternating voltage)

ω - angular velocity (s^{-1} or rad s^{-1})
t - time (s)
V_0 - peak voltage (V)

- $\tilde{V} = \tilde{Z}\tilde{I}$ (complex impedances)

$\left.\begin{array}{l} \tilde{V} \text{ - complex voltage (V)} \\ \tilde{I} \text{ - complex current (I)} \\ \tilde{Z} \text{ - complex impedance } (\Omega) \end{array}\right\}$ phasors.

- $\tilde{Y} = \dfrac{1}{\tilde{Z}}$ (complex admittance)

$\tilde{Y}$ - complex admittance (S)

- $\tilde{Z}_R = R$ (complex impedance of resistor)
- $\tilde{Z}_C = \dfrac{1}{j\omega C}$ (complex impedance of capacitor)

j is the same as i, ie. $j = \sqrt{-1}$

- $\tilde{Z}_L = j\omega L$ (complex impedance of inductor)
- $\tilde{Z}_{eq} = \tilde{Z}_1 + \tilde{Z}_2$ (complex impedances in series)
- $\dfrac{1}{\tilde{Z}_{eq}} = \dfrac{1}{\tilde{Z}_1} + \dfrac{1}{\tilde{Z}_2}$ (complex impedances in parallel)

$\tilde{Z}_{eq}$ = equivalent complex impedance (Ω)

- $I_{rms} = \dfrac{I_0}{\sqrt{2}}$ (root mean square current)
- $V_{rms} = \dfrac{V_0}{\sqrt{2}}$ (root mean square voltage)
- $P_{rms} = V_{rms} I_{rms}$ (mean power)
- $P = \frac{1}{2} V_0 I_0 \cos\phi = V_{rms} I_{rms} \cos\phi$ (mean power)

$\cos\phi$ - power factor.

- $\tan\phi = \dfrac{Im(\tilde{Z})}{Re(\tilde{Z})}$ (power factor)
- $\mathcal{E} = BAN\omega \sin \omega t$ (emf in rotating coil)

N - no. of turns
ω - angular velocity (s^{-1})

Quantum Phenomena

- $W_{total} = -eV_0 = E_{k\,max} = \frac{1}{2}mv^2$ (work done by electron)

v - maximum velocity of electron (ms^{-1})

m - mass of electron (kg)

V_0 - stopping potential (V)

e - charge on electron (C)

- $E = hf = hc/\lambda$ (Photoelectric eqn)

E - energy of photon (eV or J)

h - Planck's constant (Js)

f - frequency of photon (Hz)

c - speed of light (ms^{-1})

λ - wavelength of photon (m)

- $hf > \phi$ (threshold frequency)

f - frequency required to emit photon (Hz)

ϕ - work function (eV or J)

- $E = pc$ (photon momentum)

p - momentum ($kgms^{-1}$)

- $eV_{Ac} = hf_{max} = \frac{hc}{\lambda_{min}}$ (Bremsstrahlung equation)

V_{Ac} - accelerating voltage (V)

f_{max} - maximum frequency (Hz)

λ_{min} - minimum wavelength (m)

- $\lambda' - \lambda = \frac{h}{mc}(1 - \cos\phi)$ (compton scattering)

λ' - wavelength of scattered radiation (m)

λ - wavelength of incident radiation (m)

m - electron rest mass (kg)

ϕ - angle of deflection (rad or °)

- $E_{min} = 2mc^2$ (pair production for electron)

E_{min} - minimum energy for pair production (eV or J)

- $\hbar = \frac{h}{2\pi}$ (reduced Planck constant)

h - Standard Planck constant (Js)

- $\Delta x \Delta p \geq \frac{\hbar}{2}$ (Heisenberg uncertainty principle, pos + momentum)

Δx - position uncertainty (m)
Δp - momentum uncertainty ($kgms^{-1}$)
$\hbar$ - reduced planck constant (Js)

- $\Delta t \Delta E \geq \frac{\hbar}{2}$ (Heisenberg uncertainty principle, energy + time)

Δt - time uncertainty (s)
ΔE - energy uncertainty (J)

- $\lambda = \frac{h}{p} = \frac{h}{mv}$ (De Broglie wavelength)

p - momentum of particle ($kgms^{-1}$)
λ - de Broglie wavelength (m)

- $\lambda = \frac{h}{\sqrt{2meV_{ab}}}$ (de Broglie wavelength for electron)

V_{ab} - accelerating voltage (V)
e - charge on electron (C)
m - mass of electron (kg)

- $\Delta E = E_i - E_f = hf$ (energy levels)

ΔE - change in energy (J)
E_i - initial level energy (J)
E_f - final level energy (J)

- $L_n = mv_n r_n = n\frac{h}{2\pi}$ (Quantization of angular momentum)

L_n - orbital angular momentum at level n (kgm^2s^{-1})
m - electron mass (kg)
v_n - electron speed (ms)
r_n - radius of orbit (m)
n - principal quantum number ($n \in \mathbb{N}$)

- $r_n = \frac{\varepsilon_0 n^2 h^2}{\pi m e^2}$ (Radius of n^{th} orbit in Bohr model)

ε_0 - permittivity of free space (Fm^{-1})

- $v_n = \frac{1}{\varepsilon_0}\frac{e^2}{2nh}$ (orbital velocity of n^{th} orbit in Bohr model)

- $r_n = n^2 a_0$ (Bohr radius)

a_0 - Bohr radius (m)

- $E_n = -\frac{hcR}{n^2}$ (total energy)

R - Rydberg constant (m^{-1})
c - speed of light (ms^{-1})

- $\lambda_m T = 2.90 \times 10^{-3}$ mK (Wien displacement law for blackbodies.)

λ_m - peak wavelength (m)
T - temperature of blackbody (K)

- $I(\lambda) = \frac{2\pi c k_B T}{\lambda^4}$ (Rayleigh - Jeans law)

k_B - Boltzmann constant (JK^{-1})
$I(\lambda)$ - intensity as a function of wavelength (Wm^{-2})

- $I(\lambda) = \frac{2\pi h c^2}{\lambda^5} \cdot \frac{1}{(e^{\frac{hc}{\lambda k T}} - 1)}$ (Planck radiation law.)

$I(\lambda)$ - spectral emittance (Wm^{-3})
T - absolute temperature of black body. (K)

- $E = \hbar \omega$ (energy / angular velocity relation)

E - energy of particle (J / eV)
ω - angular velocity ($rad\,s^{-1}$)

- $p = \hbar k$ (momentum / wavenumber relation)

p - momentum ($kgms^{-1}$)
k - wavenumber

- $-\frac{\hbar^2}{2m} \frac{\partial^2 \Psi(x,t)}{\partial x^2} + u(x)\Psi(x,t) = i\hbar \frac{\partial \Psi(x,t)}{\partial t}$ (General Schrödinger eqn.)

m - mass of particle (kg)
$\hbar$ - reduced planck constant (Js)
$\Psi(x,t)$ - wavefunction
$u(x)$ - potential energy function (J)
i - $\sqrt{-1}$

- $\Psi(x,t) = A[\cos(kx-\omega t) + i\sin(kx-\omega t)] = Ae^{i(kx-\omega t)}$ (Wavefunction)

A - amplitude (can be complex.)

- $\Psi(x,t) = \Psi(x)\,e^{-\frac{iEt}{\hbar}}$ (time-dependent wavefunction)

t - time (s)

E - energy (J)

- $-\frac{\hbar^2}{2m}\frac{d^2\Psi(x)}{dx^2} + U(x)\,\Psi(x) = E\,\Psi(x)$ (time-independant Schrödinger eqn)

$\Psi(x)$ - time-independant wavefunction

m - mass (kg)

- $E_n = \frac{p_n^2}{2m} = \frac{n^2h^2}{8mL^2} = \frac{n^2\pi^2\hbar^2}{2mL^2}$ (energy levels for a particle in a box.)

P_n - momentum ($kgms^{-1}$)

m - mass of particle (kg)

L - width of box (m)

$n \in 1, 2, 3, \ldots$

- $\int_{-\infty}^{\infty} |\Psi(x)|^2\,dx = 1$ (Normalization condition)

$\Psi(x)$ - time-independant wavefunction

- $\Psi_n(x) = \sqrt{\frac{2}{L}}\sin\left(\frac{n\pi x}{L}\right)$ (Particle in box time-independant wavefunction)

L - length of box (m)

$n \in 1, 2, 3, \ldots$