STPM/SUEC PHYSICS FORMULAE SHEET

Physical quantities and units

Dimensions of physical quantities

Quantity	SI unit	Symbol	Dimension
time	second	s	T
mass	kilogram	kg	M
length	metre	m	L
current	ampere	A	I
temperature	kelvin	K	θ
amount of substance	mole	mol	N
light intensity	candela	cd	

Prefix	Power	Abbreviation
peta	10^{15}	P
tera	10^{12}	T
giga	10^{9}	G
mega	10^{6}	M
kilo	10^{3}	K
hector	10^{2}	H
deka	10^{1}	da
deci	10^{-1}	d
centi	10^{-2}	c
milli	10^{-3}	m
micro	10^{-6}	μ
nano	10^{-9}	n
pico	10^{-12}	p
femto	10^{-15}	f

Scalar and vectors

Resultant vector, $C = \text{vector} A + \text{vector } B$

x-component: $F_x = F\cos\theta$

y-component: $F_y = F\sin\theta$

angle $\theta = tan^{-1}\left(\frac{F_y}{F_x}\right)$

$$F = \sqrt{{F_x}^2 + {F_y}^2}$$

$$P \cdot Q = PQ\cos\theta, |P \times Q| = PQ\sin\theta$$

Uncertainties in measurements

If $l \pm \Delta l$, where Δl is absolute uncertainty

Fractional uncertainty $= \frac{\Delta l}{l}$

Percentage uncertainty $= \frac{\Delta l}{l} \times 100\%$

Kinematics and dynamics

Linear motion and projectile

$$v = \frac{s}{t}(ms^{-1})$$

$$v^2 = u^2 + 2as$$

$$v = u + at$$

$$s = ut + \frac{1}{2}at^2$$

$$a = \frac{v-u}{t}(ms^{-2})$$

$$a = \frac{1}{2}(u+v)t$$

Greatest height, $H = \frac{u^2 sin^2\theta}{2g}$

Range , $R = \frac{u^2 \sin 2\theta}{g}$

Time of flight, $T = \frac{2u\sin\theta}{2g}$

Maximum range, $R = \frac{u^2}{g}$,where $\theta = 45\,^\circ$

Dynamics

Newton's law of motion

Newton's First Law: a body at rest will remain at rest, a body that is moving will continue with constant velocity, unless acted upon by an external force

Newton's Second Law: the rate of change of momentum of a body is directly proportional to the resultant force acting on it and is in the same direction as the resultant force

Force, $F = ma$(unit: N or $kgms^{-2}$)

Impulse, $Ft = mv - mu$(unit: Ns or $kgms^{-1}$)

Newton's Third Law: every action has a reaction which is of the same magnitude but opposite in direction

Linear momentum and its conservation

momentum, $p = mv$ (unit: $kgms^{-1}$)

total linear momentum before collision = total linear momentum after collision

$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

Elastic and Non-elastic collisions

Elastic collision is where kinetic energy is conserved

$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$

Non-elastic collision is where kinetic energy is not conserved

$m_1u_1 + m_2u_2 = (m_1 + m_2)v$

Centre of mass

Coordinates of center of mass

$$\bar{x} = \frac{m_1x_1 + m_2x_2 + \cdots + m_nx_n}{m_1 + m_2 + \cdots + m_n} = \frac{\sum_{i=1}^{i=n}(m_ix_i)}{\sum_{i=1}^{i=n} m_i}$$

$$\bar{y} = \frac{m_1y_1 + m_2y_2 + m_ny_n}{m_1 + m_2 + \cdots + m_n} = \frac{\sum_{i=1}^{i=n}(m_iy_i)}{\sum_{i=1}^{i=n} m_i}$$

Frictional forces

Limiting static friction, $F_s = \mu_s R$

Kinetic friction, $F_k = \mu_k R$

<u>Work, Energy and Power</u>

Work

Work done, $W = Fs = Fs\cos\theta$ (unit: Nm, J or kgm^2s^{-2})

Potential energy and kinetic energy

Kinetic energy, $K = \frac{1}{2}mv^2$ (unit: J or kgm^2s^{-2})

Potential energy, $U = mgh$

Total energy, $E = K + U$

Power

$P = \frac{W}{t}$(unit: Js^{-1} or W or kgm^2s^{-3})

Efficiency

$$Efficiency = \frac{P_{output}}{P_{input}} \times 100\%$$

<u>Circular Motion</u>

Angular displacement and angular velocity

$$T = \frac{2\pi}{\omega}$$

$\omega = 2\pi f$

$v = r\omega$

Where T =period, ω =angular velocity, 2π =angular displacement of a complete circle, v =velocity, r =radius of the circle

Centripetal acceleration

$a = v\omega$

$a = r\omega^2$

$$a = \frac{v^2}{r}$$

Where a =centripetal acceleration, ω =angular velocity, v =velocity, r =radius of the circle

Centripetal force

$F = mv\omega$

$F = mr\omega^2$

$$F = \frac{mv^2}{r}$$

$$T = \frac{mv^2}{r}$$

Where F =centripetal force, m =mass, ω = angular velocity, v =velocity, r =radius of the circle, T =tension

Gravitational

Newton's law of universal gravitation

$F = -G\frac{m_1 m_2}{r^2}$

Where $G = 6.67 \times 10^{-11} m^3 kg^{-1} s^{-2}$

Gravitational field

Gravitational field strength, $E = \frac{F}{m}$

Acceleration due to gravity, $g = G\frac{M}{R^2}$ (unit: ms^{-2})

Gravitational potential

Gravitational potential energy, $U = -G\frac{Mm}{r}$

Gravitational potential, $V = -G\frac{M}{r}$ (unit: Jkg^{-1})

$gR^2 = GM$

Satellite motion in circular orbit

Velocity of satellite

$v = \sqrt{\frac{gR^2}{r}}$ or $v = \sqrt{\frac{GM}{r}}$ (unit: ms^{-1})

Total energy of satellite, $E = U + K$

$= -\frac{GmM}{r} + \frac{gmM}{2r}$

$= -\frac{GmM}{2r}$

Escape velocity

Escape velocity, $v_e = \sqrt{\frac{2GM}{R}} = \sqrt{2gR}$

Statics

Equilibrium of particles

$F_1 + F_2 + F_3 = 0$

Closed polygon

$F_1 + F_2 + F_3 + F_4 + F_5 = 0$

Equilibrium of a rigid body

Resultant force on a rigid body= $F + (-F) = 0$

$Fd = I\alpha$

where$I$ = moment of inertia of the rigid body about the axis of rotation

torque produced by a couple = Fd

where d = perpendicular distance between the two forces of magnitude F

Frictional forces

Limiting static friction, $F_r = \mu_s R$

Where μ_s =coefficient of static friction between the surface areas, R =normal reaction

Deformation of Solids

Stress and strain

Stress= $\frac{F}{A}$(unit:Nm^{-2})

Strain = $\frac{e}{I_0}$ (no unit)

Where F =force, A =cross-sectional area, e =extension, I_0 =original length

Force-extension graph and stress-strain graph

Young's modulus, $E = \frac{stress}{strain} = \frac{\frac{F}{A}}{\frac{e}{I_0}} = \frac{Fl_0}{Ae}$ (unit: Nm^{-2}, dimensions $ML^{-1}T^{-2}$)

Hooke's Law, $F = ke$

Strain energy

Work done, $\delta W = F\delta x$

Work done/ stress energy = $\frac{1}{2}Fe$

Kinetic theory of gases

Ideal gas equation

Boyle's Law	Charles' Law	Gay-Lussac's Law or Pressure Law
$p_1V_1 = p_2V_2$	$\frac{V_1}{T_1} = \frac{V_2}{T_2}$	$\frac{P_1}{T_1} = \frac{P_2}{T_2}$

Ideal Gas Equation

$pV = nRT$

$pV = nkT$

(k =Boltzmann constant, $1.38 \times 10^{-23} JK^{-1}$)

Pressure of a gas

$$p = \frac{1}{3}\rho\langle c^2\rangle$$

$$p = \frac{1}{3}nm\langle c^2\rangle$$

Molecular Kinetic Energy

Average translational kinetic energy of the random motion

$$\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT$$

Translational kinetic energy per mole on an ideal gas = $\frac{3}{2}RT$

The R.M.S Speed of Gas Molecules

$$c_{r.m.s} = \sqrt{\langle c^2\rangle} = \sqrt{\frac{3kT}{m}}$$

$$c_{r.m.s} = \sqrt{\langle c^2\rangle} = \sqrt{\frac{3RT}{m}}$$

Degrees of Freedom and Law of Equipartition of Energy

Average total energy of a molecule with f degrees of freedom = $f\left(\frac{1}{2}kT\right)$

Internal Energy of an Ideal Gas

$$U = N_A\left[f\left(\frac{1}{2}kT\right)\right] = \frac{f}{2}(N_Ak)T = \frac{f}{2}RT$$

$v_{mp} < v_{av} < v_{rms}$ and the ratio $v_{mp} : v_{av} : v_{rms}$ is $1.00 : 1.13 : 1.23$

Thermodynamics of gases

Heat Capacity

Specific heat capacity, $c = \frac{C}{m}$

Molar heat capacity, $c_m = \frac{m_x c}{1000}$

Where m =mass of substance, c = specific heat capacity, C =heat capacity

Work done by a gas

$$W = \int_{v_2}^{v_2} pdV$$

First Law of Thermodynamics

$\Delta Q = \Delta U + W$

where ΔQ =heat energy supplied, ΔU =increase in internal energy, W = work done by gas

Isothermal and Adiabatic Changes

$C_{v,m} - C_{V,m} = R$

$\gamma = \frac{C_{p,m}}{C_{V,m}}$

$C_{p,m} = \frac{f+2}{2}R$

$C_{V,m} = \frac{f}{2}R$

Ratio of principal molar heat capacities

$\gamma = \frac{C_{p,m}}{C_{V,m}} - \frac{f+2}{2}$

Heat transfer

Conduction

$\frac{dQ}{dt} = -kA\frac{d\theta}{dx}$ where

k =thermal conductivity (unit: $Wm^{-1}K^{-1}$)

A =cross-sectional area (unit: m^2)

$\frac{d\theta}{dx}$ =temperature gradient (unit: Km^{-1})

Thermal resistance= $\frac{l}{kA}$ where

l = length of rod

k =thermal conductivity

A =cross-sectional area

Convection/ radiation/global warming

Stefan -Botzman law:

$P = e\sigma AT^4, P_{net} = e\sigma A\left(T^4 - {T_0}^4\right)$

Electrostatics

Coulomb's Law $F_e = \frac{Q_1Q_2}{4\pi\varepsilon_0 r^2}$

Electric field strength $E = \frac{F}{q}$

Gauss's Law $\sum Q = \varepsilon_0\phi, \quad \phi = EA$

for a point charge $Q, E = \frac{Q}{4\pi\varepsilon_0 r^2}$

$V = \frac{Q}{4\pi\varepsilon_0 r}$

$E = -\frac{dV}{dx}$

$V = -\int_{\infty}^{r} E\,dx$

Capacitors

Energy stored in capacitor

$E = \frac{1}{2}CV^2 = \frac{1}{2}QV = \frac{1}{2}\frac{Q^2}{C}$

charging capacitor:

$I_0 = \frac{E}{R}$

$I = I_0 e^{\frac{-t}{CR}}, Q = Q_0\left(1 - e^{-\frac{t}{CR}}\right), V = E\left(1 - e^{-\frac{t}{CR}}\right)$

Discharging capacitor:$I = I_0 e^{-\frac{t}{CR}}, Q = Q_0 e^{-\frac{t}{CR}}$

$V = V_0 e^{-\frac{t}{CR}};\ I_0 = \frac{V_0}{R}$

Time constant, $\tau = CR$

Electric current

Current $I = \frac{dQ}{dt} = nAve$

Current density, $J = \frac{I}{A}$

Power,$P = VI = I^2R = \frac{V^2}{R}$

Resistivity, $\rho = \frac{RA}{\ell}$

Conductivity, $\sigma = \frac{1}{\rho} = \frac{ne^2\tau}{m}$

Temperature coefficient of resistance,

$\alpha = (R - R_0)/R_0\theta$

Direct current circuits

Emf $E = I(R + r)$

$\frac{E}{V} = \frac{R + r}{R}$

Kirchhoff's Law $\sum I = 0$ & $\sum(IR) = \sum E$

Magnetic fields

$F_m = qvB \sin\theta = BI\ell \sin\theta$

Magnetic field due to current

For a straight wire, $B = \frac{\mu_0 I}{2x\pi}$

For a circular coil, $B = \frac{\mu_0 NI}{2r}$

For a solenoid, $B = \mu_0 nI$

For two parallel conductors, force per unit length

$\frac{F}{\ell} = \frac{\mu_0 I_1 I_2}{2\pi d}$

Torque on a coil $\tau = IBAN$

Hall voltage $V_H = \frac{BI}{nte}$

Electromagnetic induction

Magnetic flux$\Phi = BA \cos\theta$

Faraday Law, $E = \frac{-d\phi}{dt}$

Induced emf, $E = B\ell v$ straight conductor

$E = \pi R^2 fB$ rotating disc

$E = NBA\omega \, sin \, \omega t$ rotating coil

$E = -L\frac{dI}{dt}, L$ =self inductance

$N\Phi = LI$

Self inductance for a solenoid, $L = \frac{\mu N^2 A}{\ell}$

Energy stored in an inductor, $E = \frac{1}{2}LI^2$

Alternating current circuits

Capacitor in ac circuit,

$V = V_0 \sin 2\pi ft$

$I = I_0 \cos 2\pi ft = I_0 \sin\left(2\pi ft + \frac{\pi}{2}\right)$

Reactance, $X_c = \frac{V_0}{I_0} = \frac{1}{2\pi fC}$

Inductor in ac circuit,

$I = I_0 \sin 2\pi ft$

$V = V_0 \cos 2\pi ft = V_0 \sin\left(2\pi ft + \frac{\pi}{2}\right)$

Reactance, $X_L = \frac{V_0}{I_0} = 2\pi fL$

Oscillations

For SHM,$-a = \omega^2 x(\omega^2$ =positive constant)

$F = -kx$ (k =positive constant)

Angular frequency, $\omega = \frac{2\pi}{T}$

Period, $T = \frac{1}{f}$

Displacement, $x = x_0 \sin \omega t \, x$

Velocity , $v = \frac{dx}{dt} = \omega x_0 \cos \omega t$

Acceleration, $a = -\omega^2 x_0 sin \, \omega t = -\omega^2 t$

Velocity, $v = \pm\omega\sqrt{{x_0}^2 - x^2}$

Total energy, $E = U + K$

Kinetic energy, $K = \frac{1}{2}m\omega^2({x_0}^2 - x^2)$

Internal energy, $U = \frac{1}{2}m\omega^2 x^2$

Total energy, $E = \frac{1}{2}m\omega^2 {x_0}^2$

Force, $F = -\frac{dU}{dx} = -m\omega^2 x$

Spring-mass system,

Period, $T = 2\pi\sqrt{\frac{m}{k}} = 2\pi\sqrt{\frac{e}{g}}$

Simple pendulum, $T = 2\pi\sqrt{\frac{l}{g}}$

Simple pendulum, $f = \frac{1}{2\pi}\sqrt{\frac{g}{l}}$

(l =length pf pendulum, g =acceleration due to gravity)

Spring-mass system, $f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$

(k =force constant, m =mass of load)

Torsional pendulum, $T = 2\pi\sqrt{\frac{I}{C}}$

Wave motion

Period, $\boldsymbol{T = \frac{1}{f}}$

$v = f\lambda$

$\phi = 2\pi\left(\frac{x}{\lambda}\right)$

Where f =frequency, v =velocity, λ =wavelength, ϕ =phase difference

Equation of progression wave

$$y = a\sin\left(\omega t \pm \frac{2\pi}{\lambda}x\right)$$

(+) for negative Ox-direction and
(-) for positive Ox-direction

Wave intensity, $I \propto a^2 \propto \frac{1}{r^2}$

Where I =intensity, a =amplitude, r =radius of sphere

Principle of superposition

Displacement of y at the point due to two waves, $y = y_1 + y_2$

Standing wave equation

$$y = \left(2a\cos\frac{2\pi}{\lambda}x\right)\sin\omega t$$

Sound waves

Fundamental frequency

Along a stretched spring

$f_0 = \frac{v}{2l} = \frac{1}{2l} = \frac{1}{2l}\sqrt{\frac{T}{u}}$(unit: Hz)

Vibrating air column, $f_0 = \frac{v}{\lambda_0} = \frac{v}{4l}$

Tube open at both ends, $f_0 = \frac{v}{\lambda_0} = \frac{v}{2l}$

Intensity level, $\beta = 10\log_{10}\frac{I}{I_0}dB$

Where I =intensity of sound, $I_0 = 1 \times 10^{-12}Wm^{-2}$

Beat frequency, $f = (f_1 - f_2)$

Doppler effect:

Apparent frequency, $f' = \left(\frac{v \pm u_0}{v \mp u_s}\right)f$

Geometrical optics

$f = \frac{r}{2}$

Refraction at curved surface,

$$\frac{n_1}{u} + \frac{n_2}{v} = \frac{n_2 - n_1}{r}$$

Lens maker's formula,

$$\frac{1}{f} = \left(\frac{n_2}{n_1} - 1\right)\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$$

Lens formula, $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

Wave optics

Interference, $\lambda = \frac{ax}{D}$

Single slit diffraction $\sin\theta = \frac{\lambda}{a}$ for 1st minimum

Diffraction grating $d\sin\theta_n = n\lambda$; highest order $n_{max} \le \frac{d}{\lambda}$

Intensity of transmitted polarized wave $I = I_0\cos^2\theta$

Speed of light $c = \frac{1}{\sqrt{\varepsilon_0\mu_0}}$

Quantum physics

Energy of photon $E = hf = \frac{hc}{\lambda}$

Einstein's photoelectric equation

$hf = W + \frac{1}{2}mv_{max}{}^2$ where

Work function $W = hf_0$; f_0 =threshold frequency

$\frac{1}{2}mv_{max}{}^2 = eV_s$; V_s =stopping potential

De Broglie wavelength, $\lambda = \frac{h}{p} = \frac{h}{mv}$

Nuclear physics

Work function, $hf = E_f - E_i$

Shortest wavelength, $\lambda_{min} = \frac{hc}{eV}$

Bragg's law: $2d\sin\theta = n\lambda$

$E = mc^2, m$ =mass defect

Radioactivity, $\frac{dN}{dt} = -\lambda N$; half life. $T_{\frac{1}{2}} = \frac{ln\,2}{\lambda}$

$N = N_0 e^{-\lambda t} = (\frac{1}{2})^n N_0$ where n =no of half life

Reaction energy, $Q = [(M_x + m_x) - (M_y + m_y)]c^2$