PHY117 Formula Sheet

Mechanics

Velocity	$\vec{v} = \frac{d\vec{r}}{dt}$
Speed	$v = \lvert\vec{v}\rvert$
Acceleration	$\vec{a} = \frac{d\vec{v}}{dt}$
Acceleration components	$a_r = \frac{v^2}{r}$ and $a_T = \frac{d\lvert\vec{v}\rvert}{dt}$
Position	$x(t) = x_0 + v_0 t + \frac{1}{2}at^2$
Velocity	$v^2 = v_0^2 + 2a\Delta x$ and $v(t) = v_0 + at$
Newton's second law	$\sum \vec{F} = m\,\vec{a}$
Newton's third law	$\vec{F}_{12} = -\vec{F}_{21}$
Gravitational force	$\vec{F}_g = m\vec{g}$
Gravitational force law	$\vec{F}_g = \frac{Gm_1m_2}{r^2}$
Newtons second law of rotation	$\sum \tau = I\alpha$
Centripetal force	$F_r = \frac{m\,v^2}{r} = mr\omega^2$
Centripetal acceleration	$\vec{a}_p = \frac{-v^2}{r}\hat{r} = -r\omega^2\hat{r}$
Angular position	$\Delta s = r\Delta\theta$ and $\theta(t) = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$
Angular velocity	$\omega = \frac{d\vartheta}{dt} = \frac{v}{r}$ and $\omega = \frac{2\pi}{T}$ and $\omega = \omega_0 + \alpha t$
Angular acceleration	$\alpha = d\omega/dt$
Angular momentum	$\vec{L} = \vec{r} \times \vec{p}$ and $\vec{L} = I\vec{\omega}$
Coordinates center of mass	$r_{cm} = \frac{\sum_i^n m_i\,r_i}{\sum_i^n m_i}$
Torque	$\vec{\tau} = \vec{r} \times \vec{F}$ and $\vec{\tau} = \frac{d\vec{L}}{dt}$
Impulse	$\vec{F}\Delta t = \Delta\vec{p} = m\Delta\vec{v}$
	$\Delta p = \int_0^T F(t)\mathrm{d}t = < F > T$
Momentum	$\vec{p} = m\vec{v}$ and $\vec{F} = d\vec{p}/dt$
Spring force	$F_s = -kx$
Static friction	$F_f = \mu_s F_N$
Kinetic friction	$F_f = \mu_k F_N$
Mechanical equilibrium	$\sum_i \vec{F}_i = 0$ and $\sum_i \vec{\tau}_i = 0$
Precession frequency	$\omega_p = \frac{r\,m\,g}{I\,\omega}$ (in gravitational field)

r	radius	m	mass	μ	friction coefficient
k	spring constant	T	periode	G	gravitational constant
I	moment of inertia	t	time	g	gravitational acceleration

Energy and work

Kinetic energy:	$K = \frac{1}{2}mv^2$
Potential energy (gravity)	$U = mgh$
Potential energy (spring)	$U = \frac{1}{2}kx^2$
Work	$W_{1\to2} = \int_1^2 \vec{F}\cdot d\vec{r}$ and $W_{1\to2} = \int_1^2 \tau\, d\theta$
Work-energy theorem	$W_{1\to2} = K_2 - K_1$ and $W = \Delta K$
Work and potential energy*	$\Delta U = -W$
Law of conservation of energy*	$K + U =$ constant

*only for conservative forces

Fluids

Hydrostatic

Pressure	$p = \frac{F}{A}$
Compressibility	$B = -\frac{p}{\frac{\Delta V}{V}}$
Pressure distribution in liquids	$p = p_0 + \rho g h$
Capillarity	$\Delta h = \frac{2\gamma\cos\theta_c}{\rho g r}$
Buoyancy	$F_b = \rho_l V_{\mathrm{dis}} g$
Bouyancy in centrifuge	$F_b = m_l\omega^2 r$
Centrifugal "force"	$F_c = m_o\omega^2 r$

Hydrodynamics

Flow rate	$I_V = \frac{\Delta V}{\Delta t} = v\,A$ where v: homogeneous velocity
Continuity equation	$I_V = v_1 A_1 = v_2 A_2$ (= constant for constant ρ)
Flow resistance	$R = \frac{\Delta p}{I_V}$
Resistance in pipe	$R = \frac{8\eta L}{\pi r^4}$
Bernoulli's equation	$p + \frac{\rho}{2}v^2 + \rho\,g\,h =$ constant
Toricelli's outflow law	$v = \sqrt{2\,g\,h}$

V_{dis}	displaced volume	V	volume	F	Force	h	height
p_0	Environmental pressure	η	viscosity	m	mass	γ	surface tension
ω	Angular velocity	r	radius	ρ	density	L	length

Solids

Stress	$\sigma = \frac{F}{A}$
Strain	$\varepsilon = \frac{\Delta L}{L}$
Young's modulus	$Y = \frac{\sigma}{\varepsilon}$
Moment of inertia	$I = \sum mr^2$
bars	$I_z = \frac{ab^3}{12}$
round profile	$I_z = \frac{\pi}{4}r^4$,

r	radius	m	mass	A	area	a, b	height, width	L	length	F	force

Thermodynamics

Ideal gases

Energy in 3D	$K = \frac{\#d.o.f.}{2} N k_B T$
Equation of state	$pV = nRT = Nk_BT$
Work	$W = \int_{V_1}^{V_2} p\,dV$
Heat capacity (constant p)	$C_p = C_V + nR$
Ratio of constants	$\gamma = \frac{C_p}{C_v}$
Adiabatic expansion	$Q = 0$ and $pV^\gamma =$ constant and $TV^{\gamma-1} =$ constant
Work in adiabatic expansion	$W = \frac{1}{\gamma-1}(p_1 V_1 - p_2 V_2)$

Real gases

Equation of state	$(p + \frac{an^2}{V^2})(V - bn) = nRT$

K	kinetic energy	N	number of particles	a	attractive force
V	volume	n	number of mol	b	correction to volume
Q	heat	k_B	Boltzmann constant	C_V	heat capacity (constant V)
p	pressure	R	gas constant		

Heat

Temp. change at constant volume	$Q = \Delta U = mc\Delta T$
Phase change	$Q = mL_f$ and $Q = mL_v$
Heat flow	$I = \frac{\Delta Q}{\Delta t} = \kappa A \frac{\Delta T}{\Delta x}$
Thermal resistance	$R = \frac{\Delta x}{\kappa A}$ and $\Delta T = IR$
Heat resistance in series	$R_{eq} = R_1 + R_2 + ...$
Heat resistance in parallel	$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + ...$
Thermal expansion (length)	$\Delta L = \alpha L_0 \Delta T$
Heat capacity	$C_v = \frac{\Delta U}{\Delta T} = (\#d.o.f.)(\frac{1}{2}nR)$
Specific heat capacity	$c = \frac{\Delta U}{\Delta T \cdot m}$ or $\frac{\Delta U}{\Delta T \text{ mole}}$
Equipartition theorem	$U = \frac{1}{2} k_B T$ per degree of freedom

Heat and work

First law	$Q = \Delta U + W$
Heat engine	$W = \lvert Q_H \rvert - \lvert Q_C \rvert$
Carnot conditions	$\frac{T_C}{T_H} = \frac{\lvert Q_C \rvert}{\lvert Q_H \rvert}$
Carnot efficiency	$\epsilon_C = 1 - \frac{\lvert Q_C \rvert}{\lvert Q_H \rvert} = 1 - \frac{T_C}{T_H}$
Performance of refrigerator	C.O.P. $= \frac{Q_c}{W}$
Heat pump efficiency	$\epsilon = \frac{Q_H}{W} = 1 +$ C.O.P.

Q_C	heat cold reservoir	T_C	temp. cold reservoir	U	internal energy
Q_H	heat hot reservoir	T_H	temp. hot reservoir	κ	thermal conductivity
Δt	time	T, ΔT	temperature	α	thermal expansion
L_f	latent heat fusion	L_v	latent heat vapor.		

Oscillations and Waves

Oscillation

Relations to ν and λ	$k = \frac{2\pi}{\lambda} \quad \omega = 2\pi\nu \quad v = \lambda\nu \quad \nu = \frac{1}{T}$
Harmonic oscillation	$x(t) = x_0 \sin(\omega_0 t + \varphi_0)$
Eigenfrequency spring oscillator	$\omega_0 = \sqrt{\frac{k_s}{m}}$ (k_s: spring constant)
Energy oscillator	$E = \frac{1}{2}\omega^2 m A^2 = \frac{1}{2} k_s A^2$

Waves

Wave equation	$\frac{\partial^2 y}{\partial x^2} = \frac{1}{v^2}\frac{\partial^2 y}{\partial t^2}$
Traveling wave	$y(x,t) = A\, sin(k\,x \pm \omega\, t)$
Standing waves	$y(x,t) = 2A\cos\omega\, t \sin k\, x$
Interference maxima n at d	$x_n = \frac{n\,\lambda\, d}{a}$, a distance between sources
Bragg's law	$2d\sin(\theta) = \lambda$
Velocity string wave	$v = \sqrt{\frac{F}{\mu}}$
Energy propagation rope	$\frac{\Delta E}{\Delta t} = \frac{1}{2}\mu\,\omega^2 v\, A^2$

Sound

Sound pressure	$p_s(x,t) = p(x,t) - p_0 = p_s^0 \sin(kx - \omega t)$
Speed of sound in liquids	$v = \sqrt{\frac{B}{\rho}}$
Intensity of sound waves in gases	$I = \frac{p_0^2}{2\rho v}$ or $I = \frac{P}{A} = (\frac{Power}{Area})$
Intensity with respect to I_{HS} in dB	$N_{dB} = 10\log_{10}\left(\frac{I}{I_{HS}}\right)$
Difference of Intensities in dB	$\Delta N_{dB} = 10\log_{10}\left(\frac{I_1}{I_2}\right)$

Electromagnetic Waves

Radiation Power	$P_S = \text{area} \cdot \epsilon\,\sigma\,(T^4 - T_0^4)$
Intensity of light	$I = \frac{P}{\text{area}} = c\,\epsilon_0\, E^2$

Optics

index of refraction	$n = \frac{c}{v}$
Law of refraction (Snell's Law)	$n_1 \sin\theta_1 = n_2 \sin\theta_2$
Law of reflection	$\theta_1 = \theta_r$
Intensity, transmission/reflection	$I_0 = I_t + I_r$
Reflected intensity	$I_r = (\frac{n_1 - n_2}{n_1 + n_2})^2 I_0$
Condition for total reflection	$\sin(\theta) \geq \frac{n_2}{n_1}$
Change of wavelength	$\lambda_2 = \lambda_1 \frac{n_1}{n_2}$
Brewster's law	$\tan\theta_p = \frac{n_2}{n_1}$
Imaging equation for lenses	$\frac{1}{f} = \frac{1}{s} + \frac{1}{s'}$
Magnification	$m = -\frac{s'}{s} = \frac{y'}{y}$

A	amplitude	λ	wavelength	ν	frequency
k	wave number	φ	phase	k_s	spring constant
ω	angular frequency	d	distance	B	bulk modulus
E	energy	μ	mass density $[\frac{\text{kg}}{\text{m}}]$	I_{HS}	hearing threshold
ρ	density	p_0	standard pressure	f	focal length
c_m	speed light (medium)	c	speed light (vacc.)	s, s'	distance object, image

Electrostatics and -dynamics

Electrostatics

Coulomb force	$F_E = \frac{k\, q_1\, q_2}{r^2}$ or $F_E = qE$
E-field of a point charge:	$\vec{E} = k\ \frac{Q}{r^2}\,\hat{r}$
Gauss' Law	$\oint_S \vec{E} \cdot \hat{n} dA = Q_{in}/\epsilon_0$
Electrical Potential difference	$\Delta V_{AB} = -\int_A^B \vec{E} \cdot d\vec{s}$
Potential energy & electric potential	$\Delta U = q\Delta V$
E-field in dielectric	$E = E_0/k_d$
Dipole	$\vec{p} = q\vec{L},\ \ U = -\vec{p} \cdot E +$ cons. and $\vec{\tau} = \vec{p} \times \vec{E}$
E-Field of a dipole	$E \approx \frac{2\,k\,q\,d}{r^3}$

Capacitance

Capacitance:	$C = \frac{Q}{\lvert\Delta V\rvert}$
Energy in capacitor	$U = \frac{1}{2}C(\Delta V)^2$
Capacitors in series	$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + ...$
Capacitors in parallel	$C_{eq} = C_1 + C_2 + ...$
Plate capacitor	$C = \kappa_d \epsilon_0\ \frac{A}{d}$
E-field in parallel capacitor	$E = \frac{V}{d}$

Electrodynamics

Ohm's law:	$V = IR$
Current	$I = \frac{\Delta Q}{\Delta t}$
Series circuits	$R_{tot} = \sum_i^n R_i,\ V_{tot} = \sum_i^n V_i$
Parallel circuits	$I_{tot} = \sum_i^n I_i,\ \frac{1}{R_{tot}} = \sum_i^n \frac{1}{R_i}$
Electric power:	$P = IV$
1D conductor:	$R = \rho \frac{L}{A}[\Omega]$
Specific resiliency (resistance)	$\rho = \rho_{20}[1 + \alpha(t_c - 20°\mathrm{C})]$
Drift velocity of charge:	$v_d = \frac{I}{n\,A\,q}$

q, Q	charge	k	coulomb constant	r	radial distance	τ	torque
A	area	U	potential energy	R	resistance		
m	mass	ϵ_0	el. permittivity (vacc.)	d	distance		
l	length	k_d	Dielectric constant	n	charge density		

Electromagnetism - Magnetism

Lorentz force	$\vec{F_L} = q \cdot \vec{v} \times \vec{B}$
Lorentz force on wire	$\vec{F_L} = I\vec{\ell} \times \vec{B}$
Magnetic susceptibility	$\chi_m = \frac{\mu}{\mu_0} - 1$
Magnetization	$M = \chi_m(\frac{B_{ext}}{\mu_0})$
Magnetic field of straight conductor	$B(r) = \frac{\mu_0 I}{2\pi r}$
Magnetic field inside solenoid	$B = \frac{\mu_0 N I}{l}$
Magnetic field inside material	$B = B_{ext} + \mu_0\, M = B_{ext}(1 + \chi_m)$
Magnetic flux	$\Phi_m = \vec{B} \cdot \vec{A} = BA\cos(\theta)$
Ampere's Law	$\oint_C \vec{B} \cdot \vec{dl} = \mu_0 I_c$
Magnetic moment	$\vec{\mu} = \mathrm{IA}\hat{n}$
Magnetic moment in B-field	$\vec{\mu} \cdot \vec{B} = -U \qquad \vec{\mu} \times \vec{B} = \vec{\tau}$
Faraday's law	$\mathcal{E} = \oint_C \vec{E} \cdot \vec{dl} = -\frac{\mathrm{d}\Phi_m}{\mathrm{d}t}$
Curvature in $\vec{B}$-field	$r = \frac{m\,v}{q\,B}$
Frequency rotation in $\vec{B}$-field	$\nu = \frac{q\,B}{2\pi\,m}$

q	charge	l	length	r	radial distance
A	area	U	potential energy	μ_0	mag. permeability (vac.)
m	mass	N	number windings coil	μ	mag. permeability (material)
τ	torque	$\mathcal{E}$	electromotive force	B_{ext}	external mag. field

Calculation rules

Logarithm

$b^x = a\ \leftrightarrow\ \log_b(a) = x$	$\log_a 1 = 0$	$\log_a a = 1$
$e^x = a\ \leftrightarrow\ \ln(a) = x$	$\log_a a^x = x$	$\log_a x^n = n\log_a x$
$\log_a xy = \log_a x + \log_a y$	$\log_a \frac{1}{b} = -\log_a b$	$\log_a b \cdot \log_b c = \log_a c$
$\log_a \frac{x}{y} = \log_a x - \log_a y$	$\log_{\frac{1}{a}} b = -\log_a b$	
$\log_a b = \frac{\log_c b}{\log_c a}$	$\log_a b = \frac{1}{\log_b a}$	$\log_{a^m} a^n = \frac{n}{m},\ m \neq 0$

Sphere geometry

Circum. of sphere	$L = 2\,r\,\pi$
Surface area of sphere	$A = 4\,r^2\,\pi$
Volume of sphere	$V = \frac{4}{3}\,r^3\,\pi$

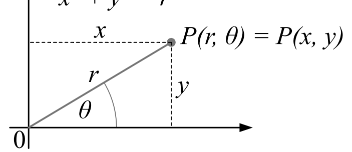
Important formulas

$0 = a\,x^2 + b\,x + c$	$x_{1,2} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$
$0 = x^2 + p\,x + q$	$x_{1,2} = -\frac{p}{2} \pm \sqrt{(\frac{p}{2})^2 - q}$
Position vector	$\vec{r_i} = (x_i, y_i, z_i)$
Dot product	$\vec{r}_1 \cdot \vec{r}_2 = x_1x_2 + y_1y_2 + z_1z_2 = \lvert\vec{r}_1\rvert\lvert\vec{r}_2\rvert\cos\theta$
Vector product	$\vec{r}_1 \times \vec{r}_2 = (y_1z_2 - y_2z_1, z_1x_2 - z_2x_1, x_1y_2 - x_2y_1)$
	$\vec{r}_1 \times \vec{r}_2 = \lvert\vec{r}_1\rvert\lvert\vec{r}_2\rvert\sin\theta\,(\hat{r}_1 \times \hat{r}_2)$
	$\hat{x}\ \times\ \hat{y} = \hat{z}$

Trigonometry

$\sin(x) = \cos(90° - x) = \cos(x - 90°)$
$\cos(x) = \sin(90° - x) = \sin(x + 90°)$
$\sin^2 x + \cos^2 x = 1$
$\tan x = \frac{\sin x}{\cos x}$
$\sin(x \pm y) = \sin x \cos y \pm \cos x \sin y$
$\cos(x \pm y) = \cos x \cos y \mp \sin x \sin y$
$\sin 2x = 2 \sin x \cos x$
$\cos 2x = \cos^2 x - \sin^2 x$
$\frac{d \sin x}{dx} = \cos x$ and $\frac{d \cos x}{dx} = -\sin x$

$x = r\cos(\theta)$
$y = r\sin(\theta)$ $\rightarrow \frac{y}{x} = \tan(\theta)$
$x^2 + y^2 = r^2$



Units and Constants

Units

Force	1 Newton (N) = $1 \frac{\text{kg}\cdot\text{m}}{\text{s}^2}$
Energy	1 Joule (J) = 1 N m = $1 \frac{\text{kg}\cdot\text{m}^2}{\text{s}^2}$
Power	1 Watt (W) = $1 \frac{\text{J}}{\text{s}} = 1 \frac{\text{kg}\cdot\text{m}^2}{\text{s}^3}$
Pressure/stress	1 Pascal (P) = $1 \frac{\text{N}}{\text{m}^2} = 1 \frac{\text{kg}}{\text{m}\cdot\text{s}^2}$ (1 bar = 10^5 Pa)
Charge	1 Coulomb (C) = 1 A s
Electric field	$1 \frac{\text{N}}{\text{C}} = 1 \frac{\text{V}}{\text{m}}$
Resistance	1 Ohm (Ω) = $1 \frac{\text{V}}{\text{A}}$
Electrical capacitance	1 Farad (F) = $\frac{\text{C}}{\text{V}} = \frac{\text{C}^2}{\text{J}}$
Magnetic field	1 Tesla (T) = $1 \frac{\text{V s}}{\text{m}^2} = 1 \frac{\text{kg}}{\text{A}\cdot\text{s}^2}$
Volume	1 m^3 = 1000 liters

Constants

Gravitational acceleration	$g = 9.81 \frac{\text{m}}{\text{s}^2}$
Gravitational constant	$G = 6.674 \cdot 10^{-11} \frac{\text{m}^3}{\text{kg}\cdot\text{s}^2}$
Boltzmann constant	$k_B = 1.381 \cdot 10^{-23} \frac{\text{J}}{\text{K}}$
Air pressure at sea level	$p_0 = 1$ atm $= 101'325$ Pa
Absolute zero	$T_0 = 0$ K $= -273.15$ °C
Universal gas constant	$R = 8.31 \frac{\text{J}}{\text{mol K}}$
Avogadro constant	$N_A = \frac{R}{k_B} = 6.022 \cdot 10^{23} \frac{1}{\text{mol}}$
Elementary charge	$e = 1.6 \cdot 10^{-19}$ C
Electron mass	$m_e = 9.11 \cdot 10^{-31}$ kg
Electrical discharge in air	$E_{max} = 3 \cdot 10^6$ V/m
Coulomb constant	$k = \frac{1}{4\pi\epsilon_0}$
Permittivity constant	$\epsilon_0 = 8.85 \cdot 10^{-12} \frac{\text{C}^2}{\text{Nm}^2}$
Speed of sound in air	$c = 340 \frac{\text{m}}{\text{s}}$
Speed of light	$c = 3 \cdot 10^8 \frac{\text{m}}{\text{s}}$
Hearing threshold	$I_{HS} = 10^{-12} \frac{\text{W}}{\text{m}^2}$ (at 1 kHz)

v_20260911

Change function ° ⇔ Radian dimension
360 ° circle= **"Deg"** = normal setting
Angle dimension = **"Rad"**

For all blue functions
(e.g. arcsin = $\sin^{-1}$: **2nd** sin)

10^x and Logarithm of ten
$\log_{10}$ (LOG) inverse:
10^x = 2nd LOG

[EE] Enters exponent.

You can enter a value in floating-decimal, fixed-decimal, or scientific notation, regardless of display format. Display format affects only results.

To enter a number in scientific notation:

1. Enter up to 10 digits for base (mantissa). If negative, press [+⇔-] after entering the mantissa.
2. Press [EE].
3. Enter 1 or 2 digit exponent. If negative, press [+⇔-] either before or after entering exponent.

1.2345 [+⇔-] [EE] [+⇔-] 65	**-1.2345 -65**

-1.2345 x 10^{-65}

Angle Units

[DRG]	Cycles angle-unit setting between degrees, radians, and grads without affecting displayed number.
[2nd] [DRG▸]	Cycles (converts) angle-unit setting between degrees, radians, and grads for display, entry, and calculation.

45	**DEG**	**45**
[2nd] [DRG▸]	**RAD**	**0.785398163**
[2nd] [DRG▸]	**GRAD**	**50.**
[2nd] [DRG▸]	**DEG**	**45.**

Trigonometric Functions

Before using the trigonometric functions ([SIN], [COS], [TAN], [2nd] [SIN-1], [2nd] [COS-1], or [2nd] [TAN-1]), select **DEG**, **RAD**, or **GRAD** with [DRG]. **Note:** Before using a DMS value in a calculation, you must convert it to decimal with [2nd] [DMS▸DD].

[DRG] (if necessary)	**DEG**	
90 [SIN]	**DEG**	**1.**
[-] 30 [COS]	**DEG**	**0.866025404**
[=]	**DEG**	**0.133974596**
1 [2nd] [SIN-1]	**DEG**	**90.**
[-] .5 [=]	**DEG**	**89.5**

Logarithmic Functions

[LOG]	15.32 [LOG]	**1.185258765**
	[+] 12.45 [LOG] [=]	**2.280428117**
[2nd] [10^x]	2 [2nd] [10^x] [-] 10 [x^2] [=]	**0.**
[LN]	15.32 [LN]	**2.729159164**
	[+] 12.45 [LN] [=]	**5.250879787**
[2nd] [e^x]	.693 [2nd] [e^x]	**1.999705661**
	[+] 1 [=]	**2.999705661**

Powers and Roots

[1/x]	8 [1/x] [+] 4 [1/x] [=]	**0.375**
[x^2]	6 [x^2] [+] 2 [=]	**38.**
[$\sqrt{x}$]	256 [$\sqrt{x}$] [+] 4 [$\sqrt{x}$] [=]	**18.**
[2nd] [x^3]	2 [2nd] [x^3] [+] 2 [=]	**10.**
[2nd] [$\sqrt[3]{x}$]	8 [2nd] [$\sqrt[3]{x}$] [+] 4 [=]	**6.**
[y^x]	5 [y^x] 3 [=]	**125.**
[2nd] [$\sqrt[x]{y}$]	8 [2nd] [$\sqrt[x]{y}$] 3 [=]	**2.**