

CONSTANTS AND CONVERSION FACTORS

Proton mass, $m_p = 1.67 \times 10^{-27}$ kg	Electron charge magnitude, $e = 1.60 \times 10^{-19}$ C
Neutron mass, $m_n = 1.67 \times 10^{-27}$ kg	1 electron volt, $1 \text{ eV} = 1.60 \times 10^{-19}$ J
Electron mass, $m_e = 9.11 \times 10^{-31}$ kg	Speed of light, $c = 3.00 \times 10^8$ m/s
Avogadro's number, $N_0 = 6.02 \times 10^{23} \text{ mol}^{-1}$	Universal gravitational constant, $G = 6.67 \times 10^{-11} \text{ m}^3/\text{kg}\cdot\text{s}^2$
Universal gas constant, $R = 8.31 \text{ J}/(\text{mol}\cdot\text{K})$	Acceleration due to gravity at Earth's surface, $g = 9.8 \text{ m/s}^2$
Boltzmann's constant, $k_B = 1.38 \times 10^{-23} \text{ J/K}$	
1 unified atomic mass unit,	$1 \text{ u} = 1.66 \times 10^{-27} \text{ kg} = 931 \text{ MeV}/c^2$
Planck's constant,	$h = 6.63 \times 10^{-34} \text{ J}\cdot\text{s} = 4.14 \times 10^{-15} \text{ eV}\cdot\text{s}$
	$hc = 1.99 \times 10^{-25} \text{ J}\cdot\text{m} = 1.24 \times 10^3 \text{ eV}\cdot\text{nm}$
Vacuum permittivity,	$\epsilon_0 = 8.85 \times 10^{-12} \text{ C}^2/\text{N}\cdot\text{m}^2$
Coulomb's law constant, $k = 1/4\pi\epsilon_0 = 9.0 \times 10^9 \text{ N}\cdot\text{m}^2/\text{C}^2$	
Vacuum permeability,	$\mu_0 = 4\pi \times 10^{-7} (\text{T}\cdot\text{m})/\text{A}$
Magnetic constant, $k' = \mu_0/4\pi = 1 \times 10^{-7} (\text{T}\cdot\text{m})/\text{A}$	
1 atmosphere pressure,	$1 \text{ atm} = 1.0 \times 10^5 \text{ N/m}^2 = 1.0 \times 10^5 \text{ Pa}$

UNIT SYMBOLS	meter,	m	mole,	mol	watt,	W	farad,	F
	kilogram,	kg	hertz,	Hz	coulomb,	C	tesla,	T
	second,	s	newton,	N	volt,	V	degree Celsius,	°C
	ampere,	A	pascal,	Pa	ohm,	Ω	electron-volt,	eV
	kelvin,	K	joule,	J	henry,	H		

PREFIXES		
Factor	Prefix	Symbol
10^9	giga	G
10^6	mega	M
10^3	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES							
θ	0°	30°	37°	45°	53°	60°	90°
$\sin \theta$	0	1/2	3/5	$\sqrt{2}/2$	4/5	$\sqrt{3}/2$	1
$\cos \theta$	1	$\sqrt{3}/2$	4/5	$\sqrt{2}/2$	3/5	1/2	0
$\tan \theta$	0	$\sqrt{3}/3$	3/4	1	4/3	$\sqrt{3}$	∞

The following conventions are used in this exam.

- I. Unless otherwise stated, the frame of reference of any problem is assumed to be inertial.
- II. The direction of any electric current is the direction of flow of positive charge (conventional current).
- III. For any isolated electric charge, the electric potential is defined as zero at an infinite distance from the charge.
- *IV. For mechanics and thermodynamics equations, W represents the work done on a system.

NEWTONIAN MECHANICS

$v = v_0 + at$	a = acceleration
$x = x_0 + v_0 t + \frac{1}{2}at^2$	F = force
$v^2 = v_0^2 + 2a(x - x_0)$	f = frequency
$\Sigma \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$	h = height
$F_{fric} \leq \mu N$	J = impulse
$a_c = \frac{v^2}{r}$	K = kinetic energy
$\tau = rF \sin \theta$	k = spring constant
$\mathbf{p} = m\mathbf{v}$	ℓ = length
$\mathbf{J} = \mathbf{F}\Delta t = \Delta \mathbf{p}$	m = mass
$K = \frac{1}{2}mv^2$	N = normal force
$\Delta U_g = mgh$	P = power
$W = F\Delta r \cos \theta$	p = momentum
$P_{avg} = \frac{W}{\Delta t}$	r = radius or distance
$P = Fv \cos \theta$	T = period
$\mathbf{F}_s = -k\mathbf{x}$	t = time
$U_s = \frac{1}{2}kx^2$	U = potential energy
$T_s = 2\pi\sqrt{\frac{m}{k}}$	v = velocity or speed
$T_p = 2\pi\sqrt{\frac{\ell}{g}}$	W = work done on a system
$T = \frac{1}{f}$	x = position
$F_G = -\frac{Gm_1m_2}{r^2}$	μ = coefficient of friction
$U_G = -\frac{Gm_1m_2}{r}$	θ = angle
	τ = torque

ELECTRICITY AND MAGNETISM

$F = \frac{kq_1q_2}{r^2}$	A = area
$\mathbf{E} = \frac{\mathbf{F}}{q}$	B = magnetic field
$U_E = qV = \frac{kq_1q_2}{r}$	C = capacitance
$E_{avg} = -\frac{V}{d}$	d = distance
$V = k\left(\frac{q_1}{r_1} + \frac{q_2}{r_2} + \frac{q_3}{r_3} + \dots\right)$	E = electric field
$C = \frac{Q}{V}$	$\mathcal{E}$ = emf
$C = \frac{\epsilon_0 A}{d}$	F = force
$U_c = \frac{1}{2}QV = \frac{1}{2}CV^2$	I = current
$I_{avg} = \frac{\Delta Q}{\Delta t}$	ℓ = length
$R = \frac{\rho \ell}{A}$	P = power
$V = IR$	Q = charge
$P = IV$	q = point charge
$C_p = C_1 + C_2 + C_3 + \dots$	R = resistance
$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \dots$	r = distance
$R_s = R_1 + R_2 + R_3 + \dots$	t = time
$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$	U = potential (stored) energy
$F_B = qvB \sin \theta$	V = electric potential or potential difference
$F_B = BI\ell \sin \theta$	v = velocity or speed
$B = \frac{\mu_0 I}{2\pi r}$	ρ = resistivity
$\phi_m = BA \cos \theta$	θ = angle
$\mathcal{E}_{avg} = -\frac{\Delta \phi_m}{\Delta t}$	ϕ_m = magnetic flux
$\mathcal{E} = B\ell v$	

FLUID MECHANICS AND THERMAL PHYSICS

$\rho = m/V$	$A = \text{area}$
$P = P_0 + \rho gh$	$e = \text{efficiency}$
$F_{buoy} = \rho Vg$	$F = \text{force}$
$A_1 v_1 = A_2 v_2$	$h = \text{depth}$
$P + \rho gy + \frac{1}{2} \rho v^2 = \text{const.}$	$H = \text{rate of heat transfer}$
$\Delta \ell = \alpha \ell_0 \Delta T$	$k = \text{thermal conductivity}$
$H = \frac{kA \Delta T}{L}$	$K_{avg} = \text{average molecular kinetic energy}$
$P = \frac{F}{A}$	$\ell = \text{length}$
$PV = nRT = Nk_B T$	$L = \text{thickness}$
$K_{avg} = \frac{3}{2} k_B T$	$m = \text{mass}$
$v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3k_B T}{\mu}}$	$M = \text{molar mass}$
$W = -P \Delta V$	$n = \text{number of moles}$
$\Delta U = Q + W$	$N = \text{number of molecules}$
$e = \left \frac{W}{Q_H} \right $	$P = \text{pressure}$
$e_c = \frac{T_H - T_C}{T_H}$	$Q = \text{heat transferred to a system}$
	$T = \text{temperature}$
	$U = \text{internal energy}$
	$V = \text{volume}$
	$v = \text{velocity or speed}$
	$v_{rms} = \text{root-mean-square velocity}$
	$W = \text{work done on a system}$
	$y = \text{height}$
	$\alpha = \text{coefficient of linear expansion}$
	$\mu = \text{mass of molecule}$
	$\rho = \text{density}$

ATOMIC AND NUCLEAR PHYSICS

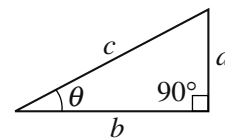
$E = hf = pc$	$E = \text{energy}$
$K_{max} = hf - \phi$	$f = \text{frequency}$
$\lambda = \frac{h}{p}$	$K = \text{kinetic energy}$
$\Delta E = (\Delta m)c^2$	$m = \text{mass}$
	$p = \text{momentum}$
	$\lambda = \text{wavelength}$
	$\phi = \text{work function}$

WAVES AND OPTICS

$v = f\lambda$	$d = \text{separation}$
$n = \frac{c}{v}$	$f = \text{frequency or focal length}$
$n_1 \sin \theta_1 = n_2 \sin \theta_2$	$h = \text{height}$
$\sin \theta_c = \frac{n_2}{n_1}$	$L = \text{distance}$
$\frac{1}{s_i} + \frac{1}{s_o} = \frac{1}{f}$	$M = \text{magnification}$
$M = \frac{h_i}{h_o} = -\frac{s_i}{s_o}$	$m = \text{an integer}$
$f = \frac{R}{2}$	$n = \text{index of refraction}$
$d \sin \theta = m\lambda$	$R = \text{radius of curvature}$
$x_m \approx \frac{m\lambda L}{d}$	$s = \text{distance}$
	$v = \text{speed}$
	$x = \text{position}$
	$\lambda = \text{wavelength}$
	$\theta = \text{angle}$

GEOMETRY AND TRIGONOMETRY

Rectangle	$A = \text{area}$
$A = bh$	$C = \text{circumference}$
Triangle	$V = \text{volume}$
$A = \frac{1}{2}bh$	$S = \text{surface area}$
Circle	$b = \text{base}$
$A = \pi r^2$	$h = \text{height}$
$C = 2\pi r$	$\ell = \text{length}$
Rectangular Solid	$w = \text{width}$
$V = \ell wh$	$r = \text{radius}$
Cylinder	
$V = \pi r^2 \ell$	
$S = 2\pi r \ell + 2\pi r^2$	
Sphere	
$V = \frac{4}{3} \pi r^3$	
$S = 4\pi r^2$	
Right Triangle	
$a^2 + b^2 = c^2$	
$\sin \theta = \frac{a}{c}$	
$\cos \theta = \frac{b}{c}$	
$\tan \theta = \frac{a}{b}$	



MECHANICS

$$v = v_0 + at$$

$$x = x_0 + v_0 t + \frac{1}{2} at^2$$

$$v^2 = v_0^2 + 2a(x - x_0)$$

$$\Sigma \mathbf{F} = \mathbf{F}_{net} = m\mathbf{a}$$

$$\mathbf{F} = \frac{d\mathbf{p}}{dt}$$

$$\mathbf{J} = \int \mathbf{F} dt = \Delta \mathbf{p}$$

$$\mathbf{p} = m\mathbf{v}$$

$$F_{fric} \leq \mu N$$

$$W = \int \mathbf{F} \cdot d\mathbf{r}$$

$$K = \frac{1}{2} mv^2$$

$$P = \frac{dW}{dt}$$

$$P = \mathbf{F} \cdot \mathbf{v}$$

$$\Delta U_g = mgh$$

$$a_c = \frac{v^2}{r} = \omega^2 r$$

$$\boldsymbol{\tau} = \mathbf{r} \times \mathbf{F}$$

$$\Sigma \boldsymbol{\tau} = \boldsymbol{\tau}_{net} = I\boldsymbol{\alpha}$$

$$I = \int r^2 dm = \Sigma mr^2$$

$$\mathbf{r}_{cm} = \Sigma m\mathbf{r} / \Sigma m$$

$$v = r\omega$$

$$\mathbf{L} = \mathbf{r} \times \mathbf{p} = I\boldsymbol{\omega}$$

$$K = \frac{1}{2} I\omega^2$$

$$\omega = \omega_0 + \alpha t$$

$$\theta = \theta_0 + \omega_0 t + \frac{1}{2} \alpha t^2$$

$$a = \text{acceleration}$$

$$F = \text{force}$$

$$f = \text{frequency}$$

$$h = \text{height}$$

$$I = \text{rotational inertia}$$

$$J = \text{impulse}$$

$$K = \text{kinetic energy}$$

$$k = \text{spring constant}$$

$$\ell = \text{length}$$

$$L = \text{angular momentum}$$

$$m = \text{mass}$$

$$N = \text{normal force}$$

$$P = \text{power}$$

$$p = \text{momentum}$$

$$r = \text{radius or distance}$$

$$\mathbf{r} = \text{position vector}$$

$$T = \text{period}$$

$$t = \text{time}$$

$$U = \text{potential energy}$$

$$v = \text{velocity or speed}$$

$$W = \text{work done on a system}$$

$$x = \text{position}$$

$$\mu = \text{coefficient of friction}$$

$$\theta = \text{angle}$$

$$\tau = \text{torque}$$

$$\omega = \text{angular speed}$$

$$\alpha = \text{angular acceleration}$$

$$\phi = \text{phase angle}$$

$$\mathbf{F}_s = -k\mathbf{x}$$

$$U_s = \frac{1}{2} kx^2$$

$$x = x_{\max} \cos(\omega t + \phi)$$

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

$$T_s = 2\pi \sqrt{\frac{m}{k}}$$

$$T_p = 2\pi \sqrt{\frac{\ell}{g}}$$

$$\mathbf{F}_G = -\frac{Gm_1 m_2}{r^2} \hat{\mathbf{r}}$$

$$U_G = -\frac{Gm_1 m_2}{r}$$

ELECTRICITY AND MAGNETISM

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$$

$$\mathbf{E} = \frac{\mathbf{F}}{q}$$

$$\oint \mathbf{E} \cdot d\mathbf{A} = \frac{Q}{\epsilon_0}$$

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

$$V = \frac{1}{4\pi\epsilon_0} \sum_i \frac{q_i}{r_i}$$

$$U_E = qV = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r}$$

$$C = \frac{Q}{V}$$

$$C = \frac{\kappa \epsilon_0 A}{d}$$

$$C_p = \sum_i C_i$$

$$\frac{1}{C_s} = \sum_i \frac{1}{C_i}$$

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

$$U_c = \frac{1}{2} QV = \frac{1}{2} CV^2$$

$$R = \frac{\rho \ell}{A}$$

$$\mathbf{E} = \rho \mathbf{J}$$

$$I = Nev_d A$$

$$V = IR$$

$$R_s = \sum_i R_i$$

$$\frac{1}{R_p} = \sum_i \frac{1}{R_i}$$

$$P = IV$$

$$\mathbf{F}_M = q\mathbf{v} \times \mathbf{B}$$

$$A = \text{area}$$

$$B = \text{magnetic field}$$

$$C = \text{capacitance}$$

$$d = \text{distance}$$

$$E = \text{electric field}$$

$$\mathcal{E} = \text{emf}$$

$$F = \text{force}$$

$$I = \text{current}$$

$$J = \text{current density}$$

$$L = \text{inductance}$$

$$\ell = \text{length}$$

$$n = \text{number of loops of wire per unit length}$$

$$N = \text{number of charge carriers per unit volume}$$

$$P = \text{power}$$

$$Q = \text{charge}$$

$$q = \text{point charge}$$

$$R = \text{resistance}$$

$$r = \text{distance}$$

$$t = \text{time}$$

$$U = \text{potential or stored energy}$$

$$V = \text{electric potential}$$

$$v = \text{velocity or speed}$$

$$\rho = \text{resistivity}$$

$$\phi_m = \text{magnetic flux}$$

$$\kappa = \text{dielectric constant}$$

$$\oint \mathbf{B} \cdot d\boldsymbol{\ell} = \mu_0 I$$

$$d\mathbf{B} = \frac{\mu_0}{4\pi} \frac{I d\boldsymbol{\ell} \times \mathbf{r}}{r^3}$$

$$\mathbf{F} = \int I d\boldsymbol{\ell} \times \mathbf{B}$$

$$B_s = \mu_0 nI$$

$$\phi_m = \int \mathbf{B} \cdot d\mathbf{A}$$

$$\mathcal{E} = \oint \mathbf{E} \cdot d\boldsymbol{\ell} = -\frac{d\phi_m}{dt}$$

$$\mathcal{E} = -L \frac{dI}{dt}$$

$$U_L = \frac{1}{2} LI^2$$

GEOMETRY AND TRIGONOMETRY

Rectangle

$$A = bh$$

Triangle

$$A = \frac{1}{2}bh$$

Circle

$$A = \pi r^2$$

$$C = 2\pi r$$

Rectangular Solid

$$V = \ell wh$$

Cylinder

$$V = \pi r^2 \ell$$

$$S = 2\pi r \ell + 2\pi r^2$$

Sphere

$$V = \frac{4}{3}\pi r^3$$

$$S = 4\pi r^2$$

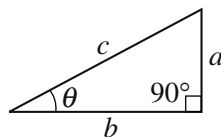
Right Triangle

$$a^2 + b^2 = c^2$$

$$\sin \theta = \frac{a}{c}$$

$$\cos \theta = \frac{b}{c}$$

$$\tan \theta = \frac{a}{b}$$



A = area

C = circumference

V = volume

S = surface area

b = base

h = height

ℓ = length

w = width

r = radius

CALCULUS

$$\frac{df}{dx} = \frac{df}{du} \frac{du}{dx}$$

$$\frac{d}{dx}(x^n) = nx^{n-1}$$

$$\frac{d}{dx}(e^x) = e^x$$

$$\frac{d}{dx}(\ln x) = \frac{1}{x}$$

$$\frac{d}{dx}(\sin x) = \cos x$$

$$\frac{d}{dx}(\cos x) = -\sin x$$

$$\int x^n dx = \frac{1}{n+1} x^{n+1}, n \neq -1$$

$$\int e^x dx = e^x$$

$$\int \frac{dx}{x} = \ln|x|$$

$$\int \cos x dx = \sin x$$

$$\int \sin x dx = -\cos x$$