OAT Bootcamp Physics Equation Sheet

LINEAR KINEMATICS		
	Formula	**Notes**
Average Velocity	$v_{avg} = \frac{d}{t}$	v_{avg} = velocity (units: m/s) d = displacement (units: m) t = time (units: s)
Displacement	$d = v_i t + \frac{1}{2}at^2$	d = displacement (units: m) v_i = initial velocity (units: m/s) a = acceleration (units: m/s^2) t = time (units: s)
Final Velocity (Time)	$v_f = v_i + at$	v_f = final velocity (units: m/s) v_i = initial velocity (units: m/s) a = acceleration (units: m/s^2) t = time (units: s)
Final Velocity (Displacement)	$v_f^2 = v_i^2 + 2ad$	v_f = final velocity (units: m/s) v_i = initial velocity (units: m/s) a = acceleration (units: m/s^2) d = displacement (units: m)
Average Acceleration	$a_{avg} = \frac{(v_f - v_i)}{t}$	a_{avg} = acceleration (units: m/s^2) v_f = final velocity (units: m/s) v_i = initial velocity (units: m/s) t = time (units: s)

FORCES		
	Formula	**Notes**
Net Force	$F_{net} = ma$	F_{net} = net force (units: N) m = mass (units: kg) a = acceleration (units: m/s^2)
Weight	$F_w = mg$	F_w = weight (units: N) m = mass (units: kg) g = acceleration due to gravity (g = 10 m/s^2)
Normal Force	$F_N = F_w cos(\theta)$	F_N = normal force (units: N) F_w = weight (units: N) m = mass (units: kg) θ = angle between horizontal and force
Friction Force	$F_f = \mu F_N$	F_f = friction force (units: N) F_N = normal force (units: N) μ = friction coefficient

GRAVITATIONAL		
	Formula	**Notes**
Gravitational Force (Two bodies)	$F = \frac{Gm_1 m_2}{d^2}$	F = gravitational force (units: N) G = gravity constant (G = 6.67 x 10^{-11} N · m^2/kg^2) m_1 = mass object 1 (units: kg) m_2 = mass object 1 (units: kg) d = distance between centers of objects (units: m)
Gravitational Acceleration (One body)	$g = \frac{Gm}{r^2}$	g = acceleration due to gravity (g = 10 m/s^2) G = gravity constant (G = 6.67 x 10^{-11} N · m^2/kg^2) m = mass single body (units: kg) r = radius of body (units: m)

ROTATIONAL & CIRCULAR MOTION		
	Formula	**Notes**
Uniform Circular Motion Velocity	$v_c = \frac{2\pi r}{T}$	v_c = velocity (units: m/s) r = radius (units: m) T = period (units: s)
Centripetal Acceleration	$a_c = \frac{v^2}{r}$	a_c = centripetal acceleration (units: m/s^2) v = velocity (units: m/s) r = radius (units: m)
Centripetal Force	$F_c = ma_c = \frac{mv^2}{r}$	F_c = centripetal force (units: N) m = mass (units: kg) a_c = centripetal acceleration (units: m/s^2) v = velocity (units m/s) r = radius (units: m)
Torque	$\tau = r \times F$ $\|\tau\| = \|r\|\|F\|sin\theta$	τ = torque vector (units: N · m) r = lever arm vector (units: m) F = force vector (units: N) θ = angle between lever arm and force **Note:** |x| denotes magnitude or absolute value
Linear Displacement	$d = r\theta$	d = linear displacement (units: m) r = radius (units: m) θ = angular displacement (units: rad)
Linear Velocity	$v = r\omega$	v = linear velocity (units: m/s) r = radius (units: m) ω = angular velocity (units: rad/s)
Linear Acceleration	$a = r\alpha$	a = linear acceleration (units: m/s^2) r = radius (units: m) α = angular acceleration (units: rad/s^2)

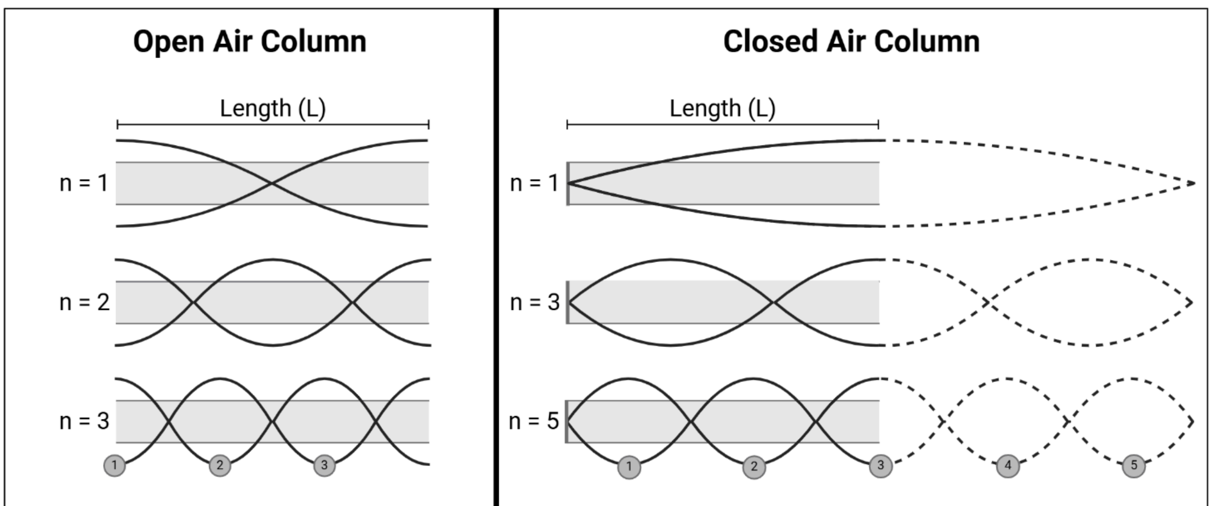
ENERGY AND MOMENTUM		
	Formula	**Notes**
Kinetic Energy	$KE = \frac{1}{2}mv^2$	KE = kinetic energy (units: J) m = mass (units: kg) v = velocity (units: m/s)
Potential Energy	$PE = mgh$	PE = potential energy (units: J) m = mass (units: kg) g = acceleration due to gravity (g = 10 m/s^2) h = height (units: m)
Total Mechanical Energy	$E_{TME} = KE + PE$	E_{TME} = total mechanical energy (units: J) KE = kinetic energy (units: J) PE = potential energy (units: J)
Work (Done by Force)	$W = Fdcos(\theta)$	W = work (units: J) F = force (units: N) d = displacement (units: m) θ = angle between F and d
Work-Energy Theorem	$W = \Delta KE$	W = work (units: J) ΔKE = change in kinetic energy (units: J)
Power	$P = \frac{W}{t}$	P = power (units: W) W = work (units: J) t = time (units: s)
Momentum	$\rho = mv$	ρ = momentum (units: kg · m/s) m = mass (units: kg) v = velocity (units: m/s)
Impulse	$\Delta\rho = F\Delta t$	Δρ = impulse (units: N · s) F = force applied (units: N) Δt = duration of time (units: s)
Inelastic Collisions	$m_1v_1 + m_2v_2 = m_3v_3$	m_1 = mass object 1 (units: kg) v_1 = velocity object 1 (units: m/s) m_2 = mass object 2 (units: kg) v_2 = velocity object 2 (units: m/s) m_3 = total mass of objects 1 & 2 (units: kg) v_3 = velocity object 3 (units: m/s)
Elastic Collisions	$m_1v_{1,i} + m_2v_{2,i} = m_1v_{1,f} + m_2v_{2,f}$	m_1 = mass object 1 (units: kg) $v_{1,i}$ = initial velocity object 1 (units: m/s) $v_{1,f}$ = final velocity object 1 (units: m/s) m_2 = mass object 2 (units: kg) $v_{2,i}$ = initial velocity object 2 (units: m/s) $v_{2,f}$ = final velocity object 2 (units: m/s)
Photon Energy	$E = \frac{hc}{\lambda}$	E = photon energy (units: J) h = Planck's constant (6.626×10^{-34} J · s) c = speed of light (3×10^8 m/s) λ = wavelength (units: m)

CENTER OF MASS		
	Formula	**Notes**
Center of Mass	$COM = \frac{m_1x_1 + m_2x_2 + ...}{m_1 + m_2 + ...}$	COM = center of mass (units: m) m = mass of object (units: kg) x = distance of object (units: m)

SIMPLE HARMONIC MOTION (SPRINGS & PENDULUMS)		
	Formula	**Notes**
Spring Force (Hooke's Law)	$F = -kx$ **Stretched:** x is positive (+) **Compressed:** x is negative (-)	F = force from the spring (units: N) k = spring constant (units: N/m) x = distance stretched/compressed (units: m)
Work (Spring)	$W = \frac{1}{2}kx^2$	W = work (units: J) k = spring constant (units: N/m) x = distance stretched/compressed (units: m)
Potential Energy (Spring)	$PE = \frac{1}{2}kx^2$	PE = potential energy (units: J) k = spring constant (units: N/m) x = distance stretched/compressed (units: m)
Period (Spring)	$T = 2\pi\sqrt{\frac{m}{k}}$	T = period (units: s) m = mass of object (units: kg) k = spring constant (units: N/m)
Period (Pendulum)	$T = 2\pi\sqrt{\frac{L}{g}}$	T = period (units: s) L = length of pendulum (unit: m) g = acceleration due to gravity ($g = 10\ m/s^2$) **Note:** the period is independent of mass
Angular Frequency	$\omega = \frac{2\pi}{T}$ $\omega = 2\pi f$	ω = angular frequency (units: rad/s) T = period (units: s) F = frequency (units: Hz)
Angular Frequency (Oscillating Spring)	$\omega = \sqrt{\frac{k}{m}}$	ω = angular frequency (units: rad/s) k = spring constant (units: N/m) m = mass (units: kg)

WAVES		
	Formula	**Notes**
Wave Velocity	$v = \lambda f$	v = velocity (units: m/s) λ = wavelength (units: m) f = frequency (units: Hz)
Period	$T = \frac{1}{f}$	T = period (units: s) f = frequency (units: Hz)
Wave / Sound Intensity	$I = \frac{P}{A} = \frac{P}{4\pi x^2}$	I = sound intensity (units: W/m^2) P = power (units: W) A = area (units: m^2) x = distance from point source (units: m)
Sound Intensity (in Decibels)	$dB = 10log\left(\frac{I}{I_0}\right)$	dB = change in decibels I = intensity of sound (units: W/m^2) I_0 = intensity of the softest sound perceivable by the human ear ($I_0 = 10^{-12}$ W/m^2)

Standing-Wave Harmonics Conventions



Open Air Column	Closed Air Column
n = 1, 2, 3... any <u>positive</u> integers	n = 1, 3, 5... any <u>odd</u> integers
$\lambda_n = \frac{2L}{n}$ $f_n = n\left(\frac{v}{2L}\right)$	$\lambda_n = \frac{4L}{n}$ $f_n = n\left(\frac{v}{4L}\right)$

λ_n = wavelength, f_n = frequency, n = harmonic number (overtone + 1), v = speed

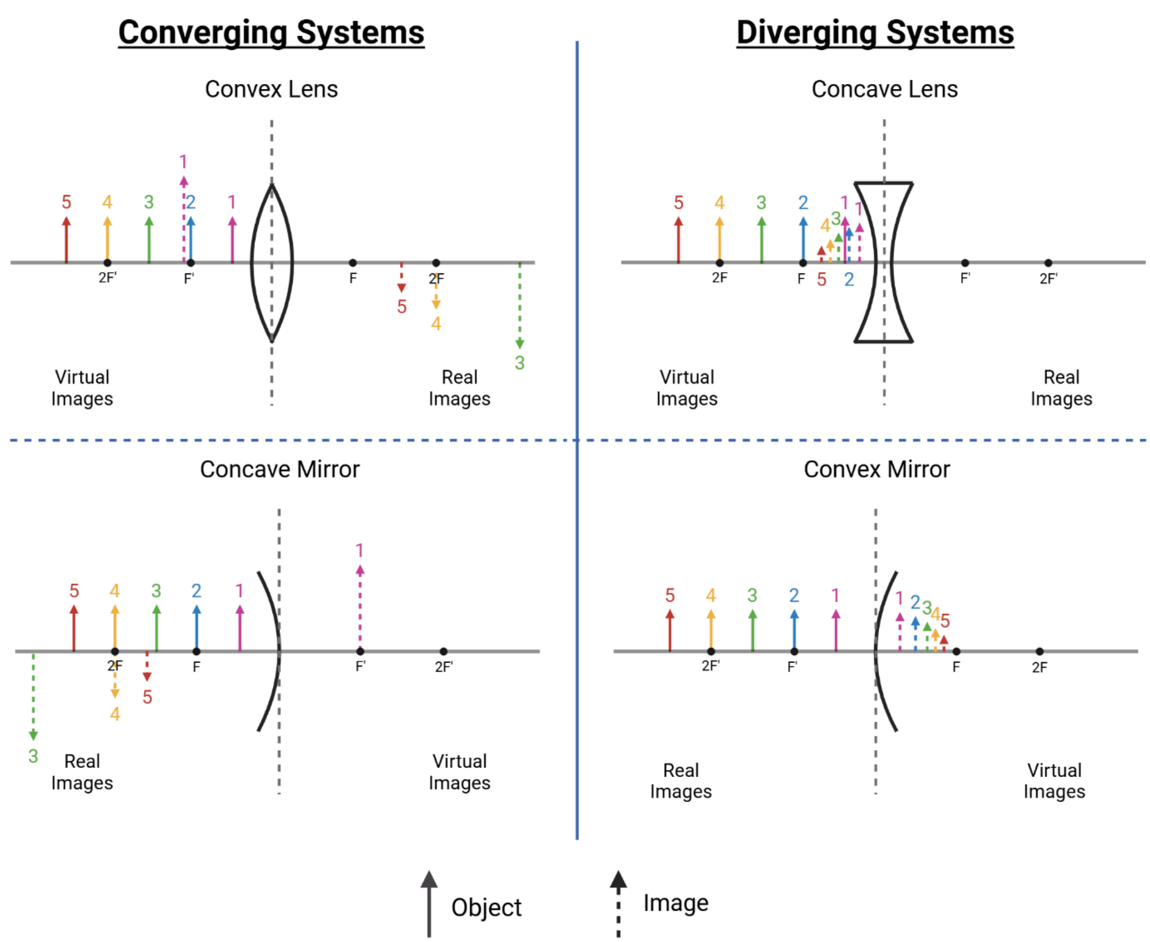
FLUID STATICS		
	Formula	**Notes**
Density	$\rho = \frac{m}{V}$	ρ = density (units: kg/m^3) m = mass (units: kg) V = volume (units: m^3)
Buoyant Forces	$F_B = \rho V g$ **For floating objects:** $F_B = mg$	F_B = buoyant force (units: N) ρ = density of fluid displaced (units: kg/m^3) V = volume of fluid displaced (units: m^3) g = acceleration due to gravity (g = 10 m/s^2) m = mass of floating object (kg)
Pressure	$P = \frac{F}{A}$	P = pressure (units: Pa) F = force (units: N) A = area (units: m^2)
Hydrostatic Pressure	$P = P_o + \rho g h$	P = pressure (units: Pa) P_O = surface level pressure (units: Pa) ρ = density (units: kg/m^3) g = acceleration due to gravity (g = 10 m/s^2) h = height (units: m)
Pascal's Principle (Hydraulics)	$\frac{F_1}{F_2} = \frac{A_1}{A_2}$	F_1 = force, region 1 (units: N) F_2 = force, region 2 (units: N) A_1 = area, region 1 (units: m^2) A_2 = area, region 2 (units: m^2)
Partially Submerged Object Relationships	$\frac{V_{sub}}{V_{obj}} = \frac{\rho_{obj}}{\rho_{fluid}}$	V_{sub} = volume of submerged portion (units: m^3) V_{obj} = volume of entire object (units: m^3) ρ_{obj} = density of object (units: kg/m^3) ρ_{fluid} = density of fluid (units: kg/m^3)

OPTICS		
	Formula	**Notes**
Index of Refraction	$n = \frac{c}{v}$	n = index of refraction of medium c = speed of light constant ($c = 3 \times 10^8$ m/s) v = speed of light in medium (units: m/s)
Snell's Law	$n_1 sin\theta_1 = n_2 sin\theta_2$	n_1= index of refraction, medium 1 θ_1= angle from normal, incident wave n_2 = index of refraction, medium 2 θ_2 = angle from normal, refracted wave
Apparent Depth	$D_{apparent} = D_{actual}(\frac{n_2}{n_1})$	$D_{apparent}$ = object's apparent depth (units: m) D_{actual} = object's actual depth (units: m) n_2 = index of refraction, medium of observer n_1 = index of refraction, medium of object
Critical Angle	$sin\theta_c = \frac{n_2}{n_1}$ For total internal reflection: $n_1 > n_2$	θ_c = angle from normal, incident wave n_1 = index of refraction, medium 1 n_2 = index of refraction, medium 2
Thin Lens Equation	$\frac{1}{o} + \frac{1}{i} = \frac{1}{f}$	o = objects distance from lens (units: cm, mm) i = image distance from lens (units: cm, mm) f = focal length (units: cm, mm)
Optical Power	$P = \frac{1}{f}$	P = power (units: D) f = focal length (units: **MUST** be in meters)
Magnification	$M = \frac{h_i}{h_o}$ $M = -\frac{i}{o}$ (+M) = *upright* image (-M) = *inverted* image	M = magnification h_i = image height (units: cm, mm) h_o = object height (units: cm, mm) o = object distance from lens (units: cm, mm) i = image distance from lens (units: cm, mm)
Image Height	$\frac{h_i}{h_o} = \frac{d_i}{d_o}$	h_o = object height (units: cm, mm) h_i = image height (units: cm, mm) d_o = object distance from lens (units: cm, mm) d_i = image distance from lens (units: cm, mm)
Focal Length (Spherical Mirrors)	$f = \frac{r}{2}$	f = focal length (units: cm, mm) r = radius of spherical mirror (units: cm, mm)

Thin Lens & Mirrors Sign Conventions

- **i (+)** → real, inverted image formed on opposite side of lens or same side of mirror
- **i (-)** → virtual, upright image formed on same side of lens or opposite side of mirror

	Focal Length (f)	Object Distance (o)	Image Distance (i)	Image Formed	Magnification (m)
Converging Systems: Convex Lens & Concave Mirror	f (+)	o < f	i (-)	**lens:** virtual, upright, in front of lens **mirror:** virtual, upright, behind mirror	magnified
		o = f	i (0)	No image	
		o > f	i (+)	**lens:** real, inverted, behind lens **mirror:** real, inverted, in front of mirror	o > 2f: reduced o = 2f: same size f < o < 2f: magnified
Diverging Systems: Concave Lens & Convex Mirror	f (-)	o < f, o = f, o > f	i (-)	**lens:** virtual, upright, in front of lens **mirror:** virtual, upright, behind mirror	reduced



Notes:

- All of the objects in this diagram are real.
- For mirrors, real images are formed on the same side as the object.
- For lenses, real images are formed on the opposite side as the object.

THERMODYNAMICS		
	Formula	**Notes**
Change in Internal Energy	$\Delta U = Q + W$ Work done BY the system = (-W) Work done ON the system = (+W)	ΔU = change in internal energy (units: J) Q = heat added to system (units: J) W = work done by/on system (units: J)
Pressure-Volume Work	$W = - P\Delta V$ Work done BY the gas = (-W) Work done ON the system = (+W)	W = work done by/on gas (units: J) P = external pressure on gas (units: atm) ΔV = change in volume (units: L)
Heat Energy Gained / Lost	$Q = mC\Delta T$	Q = heat energy gained/lost (units: J) m = mass (units: g) C = specific heat capacity (units: J/g·°C) ΔT = change temperature (units: °C or K)
Linear Thermal Expansion	$\Delta L = \alpha L_0 \Delta T$	ΔL = change in object length (units: m) L_0 = original object length (units: m) α = linear expansion coefficient (units: $°C^{-1}$) ΔT = change in temperature (units: °C)
Ideal Gas Equation	$PV = nRT$	P = pressure (units: atm, Pa) V = volume (units: L, m^3) n = moles of gas (units: mol) T = absolute temperature (units: K) R = gas constant (L·atm/mol·K, J/mol·K)
	Version 1 Use **R = 0.0821 L·atm/mol·K** when: • solving for (P) in atm • solving for (V) in L	Version 2 Use **R = 8.31 J/mol·K** when: • Solving for (P) in Pa • Solving for (V) in m^3

DC CIRCUITS		
	Formula	**Notes**
Voltage (Ohm's Law)	$V = IR$	V = voltage (units: V) I = current (units: A) R = resistance (units: Ω)
Power	$P = IV = I^2R = \frac{V^2}{R}$	P = power (units: W) I = current (units: A) V = voltage (units: V) R = resistance (units: Ω)
Current	$I = \frac{q}{t}$	I = current (units: A) q = charge (units: C) t = time (units: s)
Resistance (of wire)	$R = \frac{\rho L}{A}$	R = resistance (units: Ω) ρ = resistivity constant (units: Ω·m) L = length of wire (units: m) A = area of wire (units: m^2)
Equivalent Capacitance (Series Capacitors)	$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + ...$	C_{eq} = equivalent capacitance (units: F) C_n = individual capacitance (units: F)
Equivalent Resistance (Series Resistors)	$R_{eq} = R_1 + R_2 + R_3 + ...$	R_{eq} = equivalent resistance (units: Ω) R_n = individual resistance (units: Ω)
Equivalent Capacitance (Parallel Capacitors)	$C_{eq} = C_1 + C_2 + C_3 + ...$	C_{eq} = equivalent capacitance (units: F) C_n = individual capacitance (units: F)
Equivalent Resistance (Parallel Resistors)	$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ...$	R_{eq} = equivalent resistance (units: Ω) R_n = individual resistance (units: Ω)
Charge (on a Capacitor)	$Q = CV$	Q = charge (units: C) C = capacitance (units: F) V = voltage differential (units: V)
Energy (in a Capacitor)	$E = \frac{1}{2}CV^2$	E = energy (units: J) C = capacitance (units: F) V = voltage differential (units: V)

ELECTROSTATICS		
	Formula	**Notes**
Coulomb's Law	$F = \frac{k\lvert q_1\rvert\lvert q_2\rvert}{x^2}$	F = electric force (units: N) k = Coulomb's constant (k = 9 × 10^9 N·m^2/C^2) q_1 = charge 1 magnitude (units: C) q_2 = charge 2 magnitude (units: C) x = distance between charges (units: m)
Electric Field	$E = \frac{F}{q}$	E = electric field strength (units: N/C or V/m) F = force (units: N) q = charge (units: C)
Electric Field of a Point Charge	$E = \frac{k\lvert q\rvert}{x^2}$ +q = direction of E is radially outwards -q = direction of E is radially inwards	E = electric field strength (units: N/C or V/m) q = point charge (units: C) k = Coulomb's constant of 9 × 10^9 (units: Nm^2/C^2) x = distance from point charge q (units: m)
Electric Potential (Point Charge)	$V = \frac{kq}{r}$	V = electric potential (units: V) q = charge (units: C) k = Coulomb's constant (k = 9 × 10^9 N·m^2/C^2) r = distance from source charge (units: m)
Electric Potential Energy	$\Delta U = q\Delta V$	ΔU = change in electric potential energy (units: J) q = charge (units: C) ΔV = change in electric potential (units: V)

Sine & Cosine		
Angle	**Sin**	**Cos**
0°	0	1
30°	1/2	$\sqrt{3}/2$
45°	$1/\sqrt{2}$	$1/\sqrt{2}$
60°	$\sqrt{3}/2$	1/2
90°	1	0