Sec. 1:

Velocity: \( v = \frac{dx}{dt} \) = slope of \( x \) vs. \( t \)
Average velocity: \( v_{av} = \frac{\Delta x}{\Delta t} \)

Acceleration: \( a = \frac{dv}{dt} \) = slope of \( v \) vs. \( t \)
Average acceleration: \( a_{av} = \frac{\Delta v}{\Delta t} \)

Motion with constant acceleration:

\[
\begin{align*}
\Delta x &= v_{av}t \\
\Delta x &= v_i t + \frac{1}{2} at^2 \\
\Delta x &= v_i t + \frac{1}{2} a t^2 \\
\Delta x &= v_i^2 + 2 a \Delta x \\
g &= 9.8 \text{ m/s}^2 = 32.2 \text{ ft/s}^2
\end{align*}
\]

Sec. 2: Memorize: Definitions of trig functions, and Pythagorean theorem.

Graphical vector addition:

- Head to tail method:
- Parallelogram rule:

Unit vectors:

\[
|\hat{i}| = |\hat{j}| = |\hat{k}| = 1
\]

If \( \vec{A} = A_x \hat{i} + A_y \hat{j} + A_z \hat{k} \) and \( \vec{B} = B_x \hat{i} + B_y \hat{j} + B_z \hat{k} \) then

\[
\begin{align*}
\vec{A} + \vec{B} &= (A_x + B_x) \hat{i} + (A_y + B_y) \hat{j} + (A_z + B_z) \hat{k} \\
n\vec{A} &= nA_x \hat{i} + nA_y \hat{j} + nA_z \hat{k} \quad (n = \text{some scalar}) \\
\vec{A} - \vec{B} &= \vec{A} + (-\vec{B}) \\
|\vec{A}| &= \sqrt{A_x^2 + A_y^2 + A_z^2}
\end{align*}
\]
Sec. 3:
Memorize: Newton’s three laws, and relationship between weight and mass.

Static friction: \( f_s \leq \mu_s n \)  
Kinetic (sliding) friction: \( f_k = \mu_k n \)
\( f = \) force of friction,  \( \mu = \) coefficient of friction,  \( n = \) normal force

Sec. 4:
Projectiles: Treat each component like one dimensional motion.

Horizontal range:
\[
R = \frac{v_i^2 \sin(2\theta)}{g}
\]

Centripetal force:
\[
F = \frac{m v^2}{r}
\]

Centripetal acceleration:
\[
a = \frac{v^2}{r}
\]

Sec. 5:
Memorize: Formulas for kinetic energy, gravitational potential energy and total energy. Understand conservation of energy.

Dot product: \( \vec{A} \cdot \vec{B} = |\vec{A}| |\vec{B}| \cos \theta = A_x B_x + A_y B_y + A_z B_z \)

Work: \( W = \vec{F} \cdot \vec{s} \)  \( \vec{F} = \) force,  \( \vec{s} = \) displacement \( (W = \int \vec{F} \cdot d\vec{s} \) if force is not constant.\)

Work-energy theorem:
\[
W = \Delta KE \quad (W = \text{work done by any kinds of forces})
\]

or
\[
E_i + W_{nc} = E_f \quad (W_{nc} = \text{work done by non-conservative forces}).
\]

Sec. 6:
Memorize: Formula for momentum. Understand conservation of momentum.

Power: \( P = \frac{dE}{dt} \)  
Average power: \( P_{av} = \frac{W}{t} = \frac{\Delta E}{\Delta t} \)  
also, \( P = \vec{F} \cdot \vec{v} \)

Impulse-momentum theorem: \( \vec{I} = \Delta \vec{p} \) where \( \vec{I} = \vec{F} \Delta t \) and \( \vec{p} = \) momentum, not power.

Elastic collision: one where mechanical energy is conserved.

Sec. 7: REMEMBER: Some equations require use of radians.

Angular velocity: \( \omega = \frac{d\theta}{dt} \)  
Average angular velocity: \( \omega_{av} = \frac{\Delta \theta}{\Delta t} \)

Angular acceleration: \( \alpha = \frac{d\omega}{dt} \)  
Average angular acceleration: \( \alpha_{av} = \frac{\Delta \omega}{\Delta t} \)

Tangential displacement, velocity, and acceleration:  
\( s = r \theta \quad v_T = r \omega \quad a_T = r \alpha \)

Motion with constant angular acceleration:
\[
\Delta \theta = \omega_{av} t \quad \omega_{av} = \frac{1}{2}(\omega_i + \omega_f) \quad \omega_f = \omega_i + \alpha t \\
\Delta \theta = \omega_i t + \frac{1}{2} \alpha t^2 \quad \omega_f^2 = \omega_i^2 + 2 \alpha \Delta \theta
\]
Moments of inertia:
Particle of mass \( m \), following orbit of radius \( r \): \( I = mr^2 \). System of such particles: \( I = \Sigma mr_i^2 \)

Rigid bodies, total mass = \( M \), outside radius = \( R \)
Hoop or tube, rotating about center: \( I = MR^2 \)
Solid cylinder or disk, rotating about center: \( I = \frac{1}{2}MR^2 \)
Solid sphere, rotating about center: \( I = \frac{2}{5}MR^2 \)
Thin spherical shell, rotating about center: \( I = \frac{2}{3}MR^2 \)
Thin rod, length \( L \), rotating about center: \( I = \frac{1}{12}ML^2 \)
Thin rod, length \( L \), rotating about one end: \( I = \frac{1}{3}ML^2 \)

Rotational version of Newton's 2\(^{\text{nd}}\) law: \( \Sigma \vec{r} = I\alpha \)
Rotational kinetic energy: \( KE_R = \frac{1}{2}I\omega^2 \)

**Sec. 8**

Cross product:
\( \vec{A} \times \vec{B} = |\vec{A}||\vec{B}|\sin \theta \hat{n} \)

Torque: \( \vec{\tau} = \vec{r} \times \vec{F} \) (\( \vec{\tau} \) points along thumb if fingers point in direction of rotation.)

First & second conditions of equilibrium: 1. \( \Sigma \vec{F} = 0 \) 2. \( \Sigma \vec{\tau} = 0 \)

**Sec. 9**

Total kinetic energy: \( KE = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2 \)

Work done by a torque: \( W = \vec{\tau} \theta \) (\( W = \int \vec{\tau} \cdot d\vec{\theta} \) if \( \vec{\tau} \) is not constant.)

Angular momentum: \( \vec{L} = \vec{r} \times \vec{p} \) or \( \vec{L} = I\vec{\omega} \)

Understand conservation of angular momentum.
Sec. 10: Memorize: Relationship between frequency and period.

Hooke's law: $F = -k \ddot{x}$ (F = force, k = spring constant, x = displacement from equilibrium.)

Harmonic oscillator:

- Displacement: $x = A \cos(\omega t + \phi)$ where $\omega = 2\pi f = \sqrt{\frac{k}{m}}$ (f = frequency.)
- Velocity: $v = -v_{\text{max}} \sin(\omega t + \phi)$ where $v_{\text{max}} = \omega A$
- Acceleration: $a = -a_{\text{max}} \cos(\omega t + \phi)$ where $a_{\text{max}} = \omega^2 A$

Elastic potential energy: $U_s = \frac{1}{2} k x^2$

Pendulum: $\omega = \sqrt{\frac{g}{L}}$ ($\omega = 2\pi f$)

Sec. 11: Memorize: Relationship between wavelength, speed and frequency.

Harmonic wave traveling to the right: $y = A \sin(kx - \omega t + \phi)$
Harmonic wave traveling to the left: $y = A \sin(kx + \omega t + \phi)$

Angular wave number: $k = \frac{2\pi}{\lambda}$ Angular frequency: $\omega = 2\pi f$

Speed of string waves: $v = \sqrt{\frac{F}{\mu}}$ F = string tension (force), $\mu$ = mass per unit length

Speed of sound in air: $v = \sqrt{402T}$ $T = \text{kelvin temperature (Celsius + 273)}$

Intensity: $I = \frac{\text{power}}{\text{area}}$

Intensity vs. distance: $\frac{I_1}{I_2} = r_1^4$

Sound level in decibels: $\beta = 10 \log \left( \frac{I}{10^{-12} \text{W/m}^2} \right)$

Doppler effect: $f' = f \frac{v \pm v_o}{v \mp v_s}$ Top: toward Bottom: away

$v = \text{speed of waves}, v_o = \text{observer’s speed}, v_s = \text{source’s speed}$

Sec. 12: Memorize: Ideal gas law.

Law of universal gravitation:

$G = 6.67 \times 10^{-11} \text{ N}\cdot\text{m}^2/\text{kg}^2$

Kepler’s laws:

1. Orbits are elliptical, with sun at one focus.
2. Line from sun to planet sweeps through equal areas in equal times.
3. $T^2 = \frac{4\pi^2}{G(m_1 + m_2)} a^3$ $T =$ period, $a =$ semi-major axis
Sec. 13: Change in length: $\Delta L = L_0 \alpha \Delta T$

Change in volume: $\Delta V = V_0 \beta \Delta T \quad \beta \approx 3 \alpha$

Heat flow due to a change of temperature: $Q = m c \Delta T \quad c =$ specific heat

Heat flow due to a change of state $Q = mL_f$ or $Q = mL_v \quad L =$ heat of fusion or vaporization

Conduction:

$$\frac{dQ}{dt} = -kA \frac{dT}{dx}$$

$dQ/dt =$ Rate of heat flow

$k =$ Thermal conductivity

$A =$ Area $\quad \frac{dT}{dx} =$ Temp. gradient

Stefan’s Law: $P = \sigma A e T^4$

$P =$ Power Radiated, $\sigma = 5.67 \times 10^{-8} W/m^2 K^4$, $A =$ Area, $e =$ Emissivity (0 to 1) $\quad T =$ Temp.

Sec. 14: Memorize: Definitions of $P =$ pressure and $\rho =$ density.

Variation of pressure with depth: $\Delta P = -\rho g \Delta h$

Pascal’s Principle: $P$ increase at one point in an enclosed fluid $= P$ increase at any other point.

Archimedes’ Principle: Buoyant force $= \text{weight of displaced fluid} = (\rho V) g$

Equation of continuity: $A \nu =$ constant $\quad (\nu =$ speed)

Bernoulli’s equation: $P + \frac{1}{2} \rho \nu^2 + \rho gh =$ constant

MATHEMATICAL BACKGROUND:

Geometric Formulas ($r =$ radius, $h =$ height):

- Circumference of a circle or sphere: $2\pi r$
- Area of a circle: $\pi r^2$
- Area of a circular cylinder (excluding ends): $2\pi rh$
- Area of a sphere: $4\pi r^2$
- Volume of a circular cylinder: $\pi r^2 h$
- Volume of a sphere: $\frac{4}{3}\pi r^3$

Quadratic Formula: If $ax^2 + bx + c = 0$ then $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$

Logarithms: if $x = b^y$ then $\log_b(x) = y \quad (b =$ base)$

$\log (xy) = \log x + \log y \quad \log (x/y) = \log x - \log y$

$\log (x^a) = a \log x \quad \log_b (b^x) = x$
Derivatives:

If \( y = ax^n \) then \( \frac{dy}{dx} = a(nx^{n-1}) \) where \( a \) & \( n \) are constants \( \neq 0 \)

If \( y = a \) constant, then \( \frac{dy}{dx} = 0 \)

Example: If \( y = 7x^3 + 4x + 8 \), then \( \frac{dy}{dx} = 21x^2 + 4 + 0 \)

Product rule: If \( y = f(x)g(x) \), then \( \frac{dy}{dx} = \frac{df}{dx}g + g\frac{df}{dx} \) (First times the derivative of the second + second times the derivative of the first.)

Chain rule: If \( y = f(g(x)) \), then \( \frac{dy}{dx} = \frac{df}{dg}\frac{dg}{dx} \) (Derivative of what’s outside the parentheses times derivative of what’s inside the parentheses. Example: If \( y = (7x)^3 \) then \( \frac{dy}{dx} = [3(7x)^2][7] \).)

Some Fundamental Constants:

Gravitational constant: \( G = 6.672 \times 10^{-11} \) N\cdot m^2 / kg^2

Speed of light: \( c = 2.998 \times 10^8 \) m / s

Electron rest mass: \( m_e = 9.110 \times 10^{-31} \) kg

Proton rest mass: \( m_p = 1.673 \times 10^{-27} \) kg

Neutron rest mass: \( m_n = 1.675 \times 10^{-27} \) kg

Universal gas constant: \( R = 8.314 \) J/mole-K

Avogadro’s Number: \( N_0 = 6.022 \times 10^{23} \) molecules / mole

Boltzmann’s constant: \( k = 1.381 \times 10^{-23} \) J / K

Some Physical Properties:

Density of air at 20°C and 1 atmosphere _____ 1.29 kg / m³

Speed of sound in air at 20°C and 1 atm. _____ 343 m/s

Density of water at 20°C _________________ 1000 kg / m³ (=1.0 gram / cm³)

Mass of earth ___________________________ 5.99 \times 10^{24} \) kg

Radius of earth ___________________________ 6.37 \times 10^6 \) m

Standard atmospheric pressure _________ 1.013 \times 10^5 \) Pa
Approximate Coefficients of Friction:

<table>
<thead>
<tr>
<th>Surface Combination</th>
<th>μ_S</th>
<th>μ_K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood on wood</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>Steel on steel</td>
<td>0.74</td>
<td>0.57</td>
</tr>
<tr>
<td>Teflon on teflon</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Glass on glass</td>
<td>0.94</td>
<td>0.40</td>
</tr>
<tr>
<td>Rubber on dry concrete</td>
<td>1.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Rubber on wet concrete</td>
<td>0.7</td>
<td>0.5</td>
</tr>
<tr>
<td>Metal on ice</td>
<td>0.03</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Expansion Coefficients (near room temperature):

<table>
<thead>
<tr>
<th>Substance</th>
<th>α (°C⁻¹)</th>
<th>β (°C⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>24 x 10⁻⁶</td>
<td>1.12 x 10⁻⁴</td>
</tr>
<tr>
<td>Ethyl alcohol</td>
<td>1.12 x 10⁻⁴</td>
<td></td>
</tr>
<tr>
<td>Brass &amp; bronze</td>
<td>19 x 10⁻⁶</td>
<td>1.24 x 10⁻⁴</td>
</tr>
<tr>
<td>Benzene</td>
<td>1.24 x 10⁻⁴</td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>17 x 10⁻⁶</td>
<td>1.5 x 10⁻⁴</td>
</tr>
<tr>
<td>Acetone</td>
<td>1.5 x 10⁻⁴</td>
<td></td>
</tr>
<tr>
<td>Glass (ordinary)</td>
<td>9 x 10⁻⁶</td>
<td>4.85 x 10⁻⁴</td>
</tr>
<tr>
<td>Glycerin</td>
<td>4.85 x 10⁻⁴</td>
<td></td>
</tr>
<tr>
<td>Glass (pyrex)</td>
<td>3.2 x 10⁻⁶</td>
<td>1.82 x 10⁻⁴</td>
</tr>
<tr>
<td>Mercury</td>
<td>1.82 x 10⁻⁴</td>
<td></td>
</tr>
<tr>
<td>Lead</td>
<td>29 x 10⁻⁶</td>
<td>9.6 x 10⁻⁴</td>
</tr>
<tr>
<td>Gasoline</td>
<td>9.6 x 10⁻⁴</td>
<td></td>
</tr>
<tr>
<td>Steel</td>
<td>11 x 10⁻⁶</td>
<td></td>
</tr>
<tr>
<td>Concrete</td>
<td>12 x 10⁻⁶</td>
<td></td>
</tr>
<tr>
<td>Vinyl siding</td>
<td>150 x 10⁻⁶</td>
<td></td>
</tr>
</tbody>
</table>

Specific heats (at 25°C):

<table>
<thead>
<tr>
<th>Substance</th>
<th>cal/g.°C</th>
<th>J/kg.°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>0.215</td>
<td>900</td>
</tr>
<tr>
<td>Concrete</td>
<td>0.2</td>
<td>840</td>
</tr>
<tr>
<td>Copper</td>
<td>0.0924</td>
<td>387</td>
</tr>
<tr>
<td>Gold</td>
<td>0.0308</td>
<td>129</td>
</tr>
<tr>
<td>Iron &amp; Steel</td>
<td>0.107</td>
<td>448</td>
</tr>
<tr>
<td>Lead</td>
<td>0.0305</td>
<td>128</td>
</tr>
<tr>
<td>Silver</td>
<td>0.056</td>
<td>234</td>
</tr>
<tr>
<td>Tin</td>
<td>0.054</td>
<td>226</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.092</td>
<td>385</td>
</tr>
<tr>
<td>Ethyl alcohol</td>
<td>0.58</td>
<td>2400</td>
</tr>
<tr>
<td>Mercury</td>
<td>0.033</td>
<td>140</td>
</tr>
<tr>
<td>Water</td>
<td>1.00</td>
<td>4186</td>
</tr>
<tr>
<td>Steam (1atm)</td>
<td>0.48</td>
<td>2010</td>
</tr>
<tr>
<td>&amp;100°</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Heat of Fusion of water = 79.6 cal/g = 3.34 x 10⁵ J/kg
Heat of Vaporization of water = 539 cal/g = 2.26 x 10⁶ J/kg

Thermal Conductivities, in W/m.°C (solids at 25°C, gases at 20°C):

<table>
<thead>
<tr>
<th>Substance</th>
<th>W/m.°C (solids)</th>
<th>W/m.°C (gases)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>238</td>
<td></td>
</tr>
<tr>
<td>Copper</td>
<td>397</td>
<td>0.8</td>
</tr>
<tr>
<td>Gold</td>
<td>314</td>
<td>2300</td>
</tr>
<tr>
<td>Iron</td>
<td>79.5</td>
<td>0.8</td>
</tr>
<tr>
<td>Lead</td>
<td>34.7</td>
<td>2</td>
</tr>
<tr>
<td>Silver</td>
<td>427</td>
<td>0.2</td>
</tr>
<tr>
<td>Wood</td>
<td>0.08</td>
<td>0.6</td>
</tr>
<tr>
<td>Air</td>
<td>0.0234</td>
<td></td>
</tr>
<tr>
<td>Helium</td>
<td>0.138</td>
<td></td>
</tr>
<tr>
<td>Hydrogen</td>
<td>0.172</td>
<td></td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0.0234</td>
<td></td>
</tr>
<tr>
<td>Oxygen</td>
<td>0.0238</td>
<td></td>
</tr>
</tbody>
</table>
Units:

Standard SI Unit: Conversion Factors:

LENGTH  meter = m  1 m = 3.281 ft, 1 mile = 1609 m = 5280 ft, 1 inch = 2.54 cm
TIME  second = s  1 hour = 3600 s, 1 solar day = 86,400 s, 1 solar year = 3.156 x 10^7 s
MASS  kilogram = kg  1 kg weighs 2.203 lb if g = 9.80 m/s^2, 1 kg = .06852 slug
VOLUME m^3  1 Liter = 10^{-3} m^3 = 10^{-3} cm^3
SPEED m/s  1 mi/hr = 0.4470 m/s = 1.467 ft/sec
FORCE newton = N  1 N = 0.2248 pound
ENERGY & WORK joule = J  1 calorie = 4.186 J. 1 J = 0.7376 ft·lb, 1 BTU = 252 cal
POWER watt = W  1 horsepower = 745.7 W = 550 ft·lb/sec
ANGLE radian = rad  1 revolution = 360° = 2π rad
FREQUENCY hertz = Hz  1 Hz = 60 rev/min = 1 cycle/sec
IMPULSE & MOMENTUM kg·m/s = N·s
TEMPERATURE kelvin = K  T (in kelvins) = T (in Celsius) + 273.15
PRESSURE pascal = N/m^2  1 atmosphere = 1.013 x 10^5 Pa = 14.70 lb/in^2

SI prefixes:

<table>
<thead>
<tr>
<th>Power:</th>
<th>Prefix:</th>
<th>Abbreviation:</th>
<th>Power:</th>
<th>Prefix:</th>
<th>Abbreviation:</th>
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</thead>
<tbody>
<tr>
<td>10^{-24}</td>
<td>yocto</td>
<td>y</td>
<td>10^1</td>
<td>deka</td>
<td>da</td>
</tr>
<tr>
<td>10^{-21}</td>
<td>zepto</td>
<td>z</td>
<td>10^2</td>
<td>hecto</td>
<td>h</td>
</tr>
<tr>
<td>10^{-18}</td>
<td>atto</td>
<td>a</td>
<td>10^3</td>
<td>kilo</td>
<td>k</td>
</tr>
<tr>
<td>10^{-15}</td>
<td>femto</td>
<td>f</td>
<td>10^6</td>
<td>mega</td>
<td>M</td>
</tr>
<tr>
<td>10^{-12}</td>
<td>pico</td>
<td>p</td>
<td>10^9</td>
<td>giga</td>
<td>G</td>
</tr>
<tr>
<td>10^{-9}</td>
<td>nano</td>
<td>n</td>
<td>10^{12}</td>
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<td>T</td>
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<tr>
<td>10^{-6}</td>
<td>micro</td>
<td>μ</td>
<td>10^{15}</td>
<td>peta</td>
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<tr>
<td>10^{-3}</td>
<td>milli</td>
<td>m</td>
<td>10^{18}</td>
<td>exa</td>
<td>E</td>
</tr>
<tr>
<td>10^{-2}</td>
<td>centi</td>
<td>c</td>
<td>10^{21}</td>
<td>zetta</td>
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</tr>
<tr>
<td>10^{-1}</td>
<td>deci</td>
<td>d</td>
<td>10^{24}</td>
<td>yotta</td>
<td>Y</td>
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