

**Kinematics**  
 $v = \Delta x / \Delta t$ ,  $a = \Delta v / \Delta t$   
 Separate vertical and horizontal equations  
 \*Constant velocity = zero acceleration\*  
 $\Delta v = 0$ , then  $d = vt$   
 also  $d = vt = \Delta x / \Delta t$  and  $v^2 = v_0^2 + 2ad$   
 $v_{avg} = (v_0 + v) / 2$  given constant  $a$   
 $\Delta v = 0$ , then  $v = at$  and  $d = \Delta x = v_0 t + \frac{1}{2} a t^2$   
 Free Fall from Rest:  $d = \frac{1}{2} g t^2$   
 If distances equal  $d = vt = \frac{1}{2} g t^2$   
 a constant then  $v = \sqrt{g d}$   
 Free Fall:  $a = g = 10 \text{ m/s}^2$   
**Newton's Laws**  
 Newton I: object continues unless a net force  
 Newton II:  $F = ma$  (only one object)  
 When falling,  $F = W = mg$   
 $F_{net} = F_1 + F_2 + \dots + F_n = ma$   
 To add forces/vectors in different directions  
 Vectors (force/velocity/acceleration):  

 $R^2 = A^2 + B^2$   
 $B = R \cos(\theta)$   
 $A = R \sin(\theta)$   
**Friction, force**  $F_f = \mu N$   $F$  opposes movement, independent of area, only  $N$  and nature of surfaces.  $N$  is weight/perp. Newton III: Action-Reaction (two objects)  
 $F_{12} = -F_{21}$   
 $\mu$  - friction coefficient until Friction =  $mg$  then  $\mu$   
**Momentum**  
 $p = mv$  Frictionless = Conservation  
 $\Delta p = \text{impulse} = F \Delta t$   
 Impulse =  $\Delta p = F \Delta t$   
 (see Energy and Power also)  
 Momentum for collisions

**Elastic collisions**  
 $K$  and  $p$  both conserved (see below for  $K$ )  
 $v_1 = v_1$ ,  $v_2 = 0$ ,  $v = v$   
 left/right = negative velocities  
 right/up = positive velocities  
**Relativity** -  $p$  conserved (momentum loss)  
 Sticky balls for  $-mv_1 + mv_2 = (m_1 + m_2)v$   
**Energy**  
 $m = \text{mass}$  [kg],  $v = \text{speed}$  [m/s],  $h = \text{height}$  [m]  
 $g = \text{change}$  [m/s],  $V = \text{volume}$  [m<sup>3</sup>]  
 $k = \text{spring constant}$  [N/m]  
 $u = \text{displacement from equilibrium}$  [m]  
 Kinetic Energy  $KE = \frac{1}{2} mv^2$   
 Gravitational Potential Energy  $PE = mgh$   
 Electric Potential Energy  $PE = qV$   
 Spring Potential Energy  $PE = \frac{1}{2} kx^2$   
 Work =  $W = F \cdot d$   $W = \Delta KE = -\Delta PE$   
 Conservation of KE energy ( $E_1 = E_2$ )  
 $PE_1 = KE_2 = PE_2 = W_{ext}$   
 $W_{ext} = F \cdot d$   $F = \text{weight}$  [N],  $d = \text{displacement}$  [m]

$W_{ext}$  due to friction/heat loss takes energy from available, final mechanical energy  
 $W$  is the change in KE due to a force  
 $W = F \cdot d \cdot \cos(\theta)$ ,  $\theta$  is angle between  $F$  &  $d$   
 $W = -ve$  if  $F$ , and  $d$  are opposite directions  
**Power = P**  
 $P = W/t = E/t = Q/t$  (useful in all molecules)  
 Power = Avg. Force \* Constant Velocity  
 Efficiency =  $\frac{\text{work done or energy out}}{\text{work input}}$   
**Moment (M) = Torque ( $\tau$ ) [Nm]**  
 $\tau = F \cdot d \cdot \sin(\theta)$  ( $d$  is from  $F$ , to fulcrum)  
 $F_{net} = 0$ ,  $\tau_{net} = 0$  (equilibrium)  
 $\square F, D, \tau$   
 $\theta = F \cdot d \cdot \sin(\theta)$ ,  $\theta$  is angle between  $F$  and  $d$   
 Weight force should be drawn from object's center.  
 If only lifting one end,  $F_{net} = F_{net}/2$   
 If fixed into one end, set him as fulcrum  
 Your force = total force = gravity force.  
 $d = 0.5L \times \frac{mg}{2}$   
 $D$  from my end =  $L_{center} - d_{center}$

**Parabolic Motion**

**1. Find time in air**  
 $d, \square$  to  $2h$  or  $d, \square$  to  $\sqrt{d/g}$  time  
**2. Find distance**  
 $d = vt$  or  $d = \frac{1}{2} g t^2$   
**Circular/Centripetal Motion**  
 $v = \text{angular velocity (rad/s)}$   
 $R = \text{angle (rad)}$ ,  $r = \text{radius (m)}$   
 Things going in circles must obey the following equations:  
 $T$  is time for complete circle where  
 $d = 2\pi r$   $T = 1/f$   $\omega = 2\pi f = 2\pi/T$   
 Tangential velocity -  $v_t = \omega r = 2\pi r/T$   
 Centripetal acceleration -  $a_c = \omega^2 r = 4\pi^2 r/T^2$   
 Centripetal force -  $F_c = m \cdot a_c$   
 Centripetal Force ( $F_c$ ) is provided by:  
 Friction/Normal/Tension/Gravity etc.  
 Always a net force  
 $V_{avg} = \frac{\Delta x}{\Delta t}$   
 $v = \sqrt{g/h}$   $v = 2\pi/T$   
**Simple Harmonic Motion & Waves**  

 When both ends are fixed nodes, we must have integer number of half-waves long  
**Restoring force (Spring) = F = -kx**  
 $u = \text{spring constant (N/m)}$   $T = 1/f$   
 $x = \text{displacement from equilibrium (m)}$   
 $PE_{spring} = \frac{1}{2} kx^2$   $KE = \frac{1}{2} mv^2$   $E_1 = E_2$   
 $E_{total} = \frac{1}{2} kA^2$   $A = \text{amplitude (m)}$   
 Spring -  $T = 2\pi \sqrt{m/k}$  ( $m = \text{mass}$  [kg])  
 Pendulum -  $T = 2\pi \sqrt{L/g}$  ( $g = 10 \text{ m/s}^2$ )  
**Stress and Strain**  
 $\sigma = \text{stress}$ ,  $\epsilon = \text{strain}$ ,  $\text{stress} = \Delta L/L$   
 $\Delta L = \text{change in length}$  [m],  $L = \text{initial length}$  [m]  
 $\rho = \text{Young's modulus}$  [Pa] (compressive/tensile)  
 $\Delta L = \frac{F L}{A Y}$   
 $G = \text{shear modulus}$  [Pa] (on an angle)  
 $\Delta \theta = \frac{F L}{A G}$   
 $B = \text{Bulk modulus}$  [Pa]  $\frac{\Delta P}{P} = -\frac{\Delta V}{V}$   
 Modulus is always per m of object  
**Simple Pressure (static fluid)**  
 $P = \text{force/area} = F/A$   $P = \rho g h$  ( $\rho = \text{density}$  [kg/m<sup>3</sup>],  $A = \text{area}$  [m<sup>2</sup>])  
 $P = \text{Force/Area} = F/A$   
 Hydraulic lift/pressure in the fluid is equal, so  $P_1 = P_2$ , and combine with above equation:  
 $F_1/A_1 = F_2/A_2$   
**Pascal's theorem:**  
 $\rho = \sqrt{2gh}$  ( $h = \text{height}$  - opening for  $h$ )  
 For pressure between two points in a fluid:  
 $P_2 = P_1 + \rho g h$   
 \*Going down in liquid - pressure builds\*  
 $P_{avg} = \rho g h$   
 $\Delta h = \rho g h$   
 $P_{avg} = \rho g h$   
**Dynamic Pressure (moving fluid)**  
 $P_{flow} = \rho v^2$   
 $A_1 v_1 = A_2 v_2$   
 $A_1 \rho v_1^2 = A_2 \rho v_2^2$   
 Bernoulli's Equation uses  $P$  also, we can set  $h$  to 0  
 $P_1 + \rho g h_1 + \frac{1}{2} \rho v_1^2 = P_2 + \rho g h_2 + \frac{1}{2} \rho v_2^2$   
 $P_1 + \rho g h_1 + \frac{1}{2} \rho v_1^2 = (P_2 + \rho g h_2) + \frac{1}{2} \rho v_2^2$   
 $\Delta h = \frac{\rho v_2^2 - \rho v_1^2}{2\rho}$   
 Wide pipe  $\square$  high pressure  $\square$  low velocity  
 $v = \sqrt{2(P_1 - P_2) / \rho}$

**Viscosity (Fluids) (shear)**  
 $\eta = \text{viscosity coefficient}$  [Pa.s],  $r = \text{radius}$  [m]  
 $\tau = \eta \frac{dv}{dy}$ ,  $L = \text{length}$  [m],  $v = \text{velocity}$  [m/s]  
 $P_{flow} = \frac{F \cdot L}{A \eta}$   $F = \Delta P \cdot A$   
 $P_{flow} = \frac{\Delta P \cdot A^2}{8 \eta L}$   
**Reynolds #**  $R = \frac{\rho v d}{\eta}$  ( $\rho = \text{density}$ ,  $L = \text{pipe diameter}$ )  
 If  $R > 2000$  then flow is turbulent  
 If  $R < 2000$  then flow is laminar  
**buoyancy force =  $F_b$**   
 $F_b = \rho_{fluid} V_{displaced} g$   
 $m = \text{mass}$  [kg]  
 $F_b = \rho_{fluid} V_{displaced} g$  ( $\rho = 1000 \text{ kg/m}^3$ )  
 When floating, buoyant force equals the weight of the object, which equals the weight of the fluid displaced.  
**Density =  $m/V$**   $V = \text{displ}$   
 When floating:  $\frac{m_{object}}{V_{object}} = \frac{m_{fluid}}{V_{fluid}}$   
 $W_{object} = W_{fluid}$   $W = \text{weight}$  [N]  
 $F = \rho_{fluid} V_{displaced} g$   $V_{displaced} = \frac{m_{object}}{\rho_{fluid}}$   
**Geometry and Conversion**  
 $A_{cylinder} = \pi r^2$ ,  $V_{cylinder} = \pi r^2 h$ ,  $V_{sphere} = \frac{4}{3} \pi r^3$   
 $1000 \text{ mL} = 1 \text{ L}$   $1000 \text{ L} = 1 \text{ m}^3$   
 $1 \text{ m}^3 = 3.6 \text{ km}^3$   $1 \text{ m}^3 = 10,000 \text{ cm}^3$   
**Temperature Conversion**  
 $T(\text{in } K) = T(\text{in } C) + 273$   
**Diffusion** -  $x = \sqrt{2Dt}$   $x = \text{distance}$   
 $D = \text{diffusion coefficient}$  [m<sup>2</sup>/s]

**Thermal Expansion**  
 $\alpha = \text{linear expansion coefficient}$   
 $\Delta L = L_0 \alpha \Delta T$  ( $L_0 = \text{original length}$ )  
 $\Delta A = A_0 2\alpha \Delta T$  ( $A_0 = \text{area}$ )  
 $\Delta V = V_0 3\alpha \Delta T$  ( $V_0 = \text{volume}$ )  
 Holes or gaps get bigger when heated uniformly. Leave a 20 cm gap  
 $T = 273.15 \text{ K}$  for triple point Temp  
 Thermal energy moves hot to cold until two objects establish dynamic equilibrium  
**Heat**  
 Partial pressure is of individual gas in whole volume. For partial pressure:  $P_{total} = P_1 + P_2 + \dots$   
 Partial pressure =  $P_1 = \frac{n_1}{n_{total}} P_{total}$   
 $n = \text{number of gas}$ ,  $n_{total} = \text{number of all gases}$   
 $R = 8.314 \text{ J/K}$ ,  $n = 1 \text{ mole}$ ,  $T = \text{Kelvin}$   
 $N = \text{number of molecules}$ ,  $n = \text{number of moles}$   
 Conversion between moles and molecules:  
 $N = \frac{\text{mass}}{\text{molar mass}} \cdot N_A$  ( $N_A = 6 \cdot 10^{23}$ )  
**Molecular KE** ( $U$ ) is total kinetic energy  
 $U_{transl} = 3/2 N k T = 3/2 N k T$   
 $U_{rot} = 3/2 N k T = 3/2 N k T$  ( $A_2, N_2$ )  
**Diatomic KE** =  $5/2 N k T$  per molecule and  $5/2 N k T$   
 $U = 5/2 N k T$  ( $O_2, CO, H_2$ )  
 $m = \text{mass of atom}$  [kg],  $v = \text{speed}$  [m/s]  
 $\frac{1}{2} m v^2 = \frac{3}{2} k T$   
**Ideal Gas** Have small size & don't stick together. If  $T$  or  $V$  is low enough, phase change occurs rather than the following:  
 $P_{total} = P_1 + P_2 + \dots$   
 $P = \frac{N k T}{V}$   
 $P = \frac{N k T}{V}$  ( $N = \text{number of molecules}$ ,  $T = \text{temp}$  [K],  $k = 1.38 \cdot 10^{-23}$ )  
 $\frac{P_1}{T_1} = \frac{P_2}{T_2}$   $V_1 = \frac{P_2 T_1}{P_1 T_2}$   
 $P_1 \cdot \frac{V_1}{T_1} = P_2 \cdot \frac{V_2}{T_2}$   
**Heat Transfer: conduction**  
 Heat transfer =  
 $\frac{dQ}{dt} = k A \frac{\Delta T}{L}$  ( $A = \frac{1}{2} \pi r^2$ )  
 $k = \text{thermal conductivity of slab}$ ,  $d = \text{slab thickness}$ ,  $L = \text{length}$  of slab,  $A = \text{area}$ ,  $\Delta T = \text{temperature change}$   
 To find the total heat transfer through multiple layers:  
 Power =  $Q/t$   
 $\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \dots$   
 $R_{total} = 3.1$  (when  $v = 0.2 \text{ m/s}$ )  
 $R_{total} = 8.3 \cdot 10^{-4}$  (when  $v = 0.2 \text{ m/s}$ )  
 $R_{total} = A \cdot k \cdot \Delta T$  ( $k = \text{thermal conductivity}$ ,  $A = \text{area}$ )  
 Power through each layer is equal to each other and the power through all layers  
 $R_{total} = \left( \frac{L_1}{k_1 A_1} + \frac{L_2}{k_2 A_2} \right)^{-1}$   
 $\left( \frac{dQ}{dt} \right)_{total} = \left( \frac{dQ}{dt} \right)_{layer 1} = \left( \frac{dQ}{dt} \right)_{layer 2}$

**Heat Capacity/T Thermal Equilibrium**  
 $Q = mc \Delta T$   $Q_1 = Q_2 = \dots = 0$   
 $Q = \text{heat}$  [J],  $m = \text{mass}$  [kg],  $c = \text{specific heat}$  [J/kg.C]  
 $\Delta T = \text{Temperature change}$  [C] or [K]  
 Finding the final temp of 2 objects  
 $T_f = (m_1 c_1 T_1 + m_2 c_2 T_2) / (m_1 c_1 + m_2 c_2)$   
 final mass of water to cool a person (energy lost = energy gained)  
 At the end = equilibrium  
 $m = \frac{m_1 c_1 (T_1 - T_f)}{c_2 (T_f - T_2)}$   
 Phase change, Latent heat/weight:  $Q = mL$   
 Energy used to melt/solidify bonds change in state not temp. If we have a phase change and temp change then add  $Q$  and  $Q = mL + mc \Delta T$   
 $Q = \text{heat gain/loss}$   
 Use to phase change. If  $Q > 0$ , go to next phase. If  $Q < 0$ , go to previous phase.  
 How much ice is needed to cool down a tank?  $M_{ice} = \frac{m_{water} (T_{water} - T_{ice})}{L_f}$   
 Top T is for water, bottom T for ice  
**Conservation of Energy** double for when  $T_{ice} = 100$   
 If  $P_{out} = P_{in}$ , remove bottom  $P_{in}$   
 Method is plotted on a graph against  $T_{avg}$   
 $T_{avg} = \frac{T_1 + T_2}{2}$   
 $T_{avg}$  wrap causes  $RH = \text{humidity} = 100\%$   
 Water evaporation cools in the wet bulb temperature but no further. If  $RH$  is low,  $\theta$  is much smaller than  $\theta$ . They're the same at 100% RH.

**Thermodynamic chart find  $T_{avg}$  from  $m$**   
 following the wet bulb 100% RH line point line. Go down to find DB/DP temperature  
**Energy and the Body**  
 $Q$  is positive when heat transfer to system.  $W$  is positive when work is done by system on external.  
 $E = \Delta U + W + Q$   $P = W/t$  or  $E/t$  or  $Q/t$   
 $\Delta U$  is net change (initial energy) and  $W$  is work done by system. If positive if pushing in  $W$ , work [J],  $Q = \text{heat}$  [J]  
 $E = \text{energy}$  [J],  $Q = \text{heat}$  [J]  
 Efficiency  $\eta = \frac{\text{net work}}{\text{total energy}} = \frac{W}{Q_{in}}$   
 $Q_{in}$  is metabolic energy required to warm the food.  $Q_{out}$  is  $W$  done when  $E = 0$  (no net work, work done, weight loss)  
 $Q = (E - \Delta U) / (E - 1) = W \cdot (1 - \frac{1}{\eta})$   
 Thermal energy lost =  
 $\frac{\text{met work}}{\eta - 1} = \text{met work}$   
 Joule  $\square$  ignores time  
 Watt  $\square$  power  $\times$  time (seconds) = energy

**Electricity - Charge/Force/Fields**  
 $q = \text{charge of one electron}$  or one proton  
 $e = 1.6 \cdot 10^{-19}$  [C]  
 $V = q \cdot V$   
 Charge is always conserved  
 $Q_{total} = Q_{initial}$   
 $E = V \cdot d = F \cdot q$  ( $E$  is Elec. Field strength)  
 $F = V \cdot q/d$   $q = F \cdot d/V$   
 $W = V \cdot q = \text{work}$   
 $W = q E \cdot \text{displacement}$  (potential change)  
**Electricity**  $\sqrt{v/c}$  term  
 $\Delta V = \frac{Q}{4\pi \epsilon_0 r^2}$ ,  $Q = \text{charge}$  [C],  $r = \text{distance}$  between charge  
 $W(\text{Potential Energy}) = \frac{k q_1 q_2}{r}$   
 further distance = greater charge  
 $\epsilon = 9 \cdot 10^9$   
 $\epsilon = \text{charge}$  [C],  $d = \text{distance}$  between charge

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