 Constants:

\[ g = 9.8 \text{ m/s}^2 \to \text{but you may use 10 m/s}^2 \text{ in nearly all cases} \]

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

\[ k_B = 1.381 \times 10^{-23} \text{ J/K} \]

\[ N_a = 6.022 \times 10^{23} \]

\[ R = k_B N_a = 8.314 \text{ J/mol-K} \]

\[ \sigma = 5.67 \times 10^{-8} \text{ W/m}^2\text{K}^4 \]

\[ \text{Mass of Sun} = 1.991 \times 10^{30} \text{ kg} \]

\[ \text{Mass of Earth} = 5.98 \times 10^{24} \text{ kg} \]

\[ \text{Radius of Earth} = 6.38 \times 10^6 \text{ m} \]

\[ \text{Radius of Earth’s orbit} = 1.496 \times 10^{11} \text{ m} \]

\[ \text{Density of water:} \ 1000 \text{ kg/m}^3 \]

\[ \text{Density of air:} \ 1.29 \text{ kg/m}^3 \]

\[ \text{Linear exp. coeff. of copper:} \ 17 \times 10^{-6} / \text{°C} \]

\[ \text{Linear exp. coeff. of steel:} \ 11 \times 10^{-6} / \text{°C} \]

\[ \text{Specific heat of water:} \ 4186 \text{ J/kg} \cdot \text{°C} \]

\[ \text{Specific heat of ice:} \ 2090 \text{ J/kg} \cdot \text{°C} \]

\[ \text{Specific heat of steam:} \ 2010 \text{ J/kg} \cdot \text{°C} \]

\[ \text{Specific heat of aluminum:} \ 900 \text{ J/kg} \cdot \text{°C} \]

\[ \text{Latent heat of melting (water):} \ 3.33 \times 10^5 \text{ J/kg} \]

\[ \text{Latent heat of boiling (water):} \ 2.26 \times 10^6 \text{ J/kg} \]

\[ \text{Thermal conduct. of aluminum:} \ 238 \text{ J/s} \cdot \text{m} \cdot \text{°C} \]

\[ v_{air} = 343 \text{ m/s at 20° C} \]

\[ \sin(30°) = 0.5 \]

\[ \cos(30°) \approx 0.866 \]

\[ \tan(30°) \approx 0.577 \]

\[ \pi \approx 3.14 \]

Conversion factors:

\[ 1 \text{ inch} = 2.54 \text{ cm} \]

\[ 1 \text{ m}^3 = 1000 \text{ L} \]

\[ 1 \text{ atm} = 1.013 \times 10^5 \text{ Pa} = 14.7 \text{ psi} \]

\[ 325 + 9 = 404 \]

\[ 273.15 + 273.15 = 546.3 \]

\[ T_k = T_c + 273.15 \]

Other equations:

\[ x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \]

\[ V = \frac{4}{3} \pi r^3 \]

\[ v_{ave} = \frac{v_i + v_f}{2} \]

\[ T_p = \frac{9}{5} T_c + 32 \]

\[ I_{hoop} = mR^2 \]

\[ I_{disk} = (1/2) mR^2 \]

\[ I_{rod} (center) = (1/2) mL^2 \]

\[ I_{rod} (end) = (1/3) mL^2 \]

\[ \Delta L = aL_0 \Delta T \]

\[ \Delta V = \beta V_0 \Delta T; \ \beta = 3\alpha \]

\[ Q = mc\Delta T; \ Q = mL \]

\[ P = \rho gh \]

\[ VFR = A_1 v_1 = A_2 v_2 \]

\[ P_1 + \frac{1}{2} \rho v_1^2 + \rho g v_1 = P_2 + \frac{1}{2} \rho v_2^2 + \rho g v_2 \]

\[ P = \frac{2}{3} \rho v^2 + \rho g v \]

\[ Q = \frac{1}{2} m v_{ave}^2 = \frac{3}{2} k_B T \]

\[ \Delta Q = k_B T_2 - T_1 \]

\[ P = e c o A T^4 \]

\[ |W_{on} (g)| = \text{area under P-V curve} \]

\[ = |P \Delta V| \quad \text{(constant pressure)} \]

\[ = nRT \ln (V_2 / V_1) \quad \text{(isothermal)} \]

\[ = |\Delta U| \quad \text{(adiabatic)} \]

\[ U = \frac{3}{2} N k_B T - \frac{3}{2} nRT \quad \text{(monatomic)} \]

\[ \omega = \frac{k}{m}, \quad T = 2\pi \sqrt{\frac{m}{k}} \]

\[ v = \sqrt{\frac{T}{\mu}}, \quad \mu = m/L \]

\[ \beta = 10 \log \left( \frac{I}{I_0} \right), \quad I_0 = 10^{-12} \text{ W/m}^2 \]

\[ f' = f \frac{v + v_0}{v + v_g} \]

\[ o-o/c-c: f_n = n f_1; \quad n = 1, 2, 3, ... \]

\[ o-c: f_n = n f_1; \quad n = 1, 3, 5, ... \]
Instructions:

- **Record your answers on the bubble sheet.**
- The Testing Center no longer allows students to see which problems they got right & wrong, so I strongly encourage you to **mark your answers in this test booklet.** You will get this test booklet back (but only if you **write your CID at the top of the first page**).
- You may write on this exam booklet, and are strongly encouraged to do so.
- In all problems, **ignore friction, air resistance, and the mass of all springs, pulleys, ropes, cables, strings etc.,** unless specifically stated otherwise.
- Use g = 9.8 m/s² only if there are “9.8” numbers in the answer choices; **otherwise use g = 10 m/s².**