Formula Sheet – Physics 111

10^{-15}	femto- (f)
10^{-12}	pico- (p)
10^{-9}	nano- (n)
10^{-6}	micro- (μ)
10^{-3}	milli- (m)
10^{-2}	centi- (c)
10^{3}	kilo- (k)
10^{6}	mega- (M)
10^{9}	giga- (G)
10^{12}	tera- (T)

Vectors and math

$$\left|\vec{V}\right| = V = \sqrt{V_x^2 + V_y^2} \qquad V_x = V\cos\theta$$

$$\tan\theta = \frac{V_y}{V_x} \qquad V_y = V\sin\theta$$

$$ax^2 + bx + c = 0 \quad \Rightarrow \quad x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Geometry

perimeter circle: $2\pi R$ area sphere: $4\pi R^2$

area circle: πR^2 volume sphere: $\frac{4}{3}\pi R^3$

1 revolution = 2π radians = 360^o

Conversion factors (for barbaric units)

1 yard = 3 foot = 36 inches 1 inch = 2.54 cm

1 mile = 1.609 km 1 lb = 4.448 N

1 gallon = 3.788 liters $1\ \text{m}^3 = 1000$ liters

1 atm = 1.013×10^5 Pa = 760 mm Hg 1 cal = 4.186 J 1 Cal = 1000 cal

Physical constants

$$g = 9.81\ \text{m/s}^2 \qquad G = 6.67\times10^{-11}\ \text{Nm}^2/\text{kg}^2$$

$$R = 8.314\ \frac{\text{J}}{\text{mol}\cdot\text{K}} \qquad \sigma = 5.67\times10^{-8}\ \text{W}/\left(\text{m}^2\cdot\text{K}^4\right) \qquad k = \frac{R}{N_\text{A}} = 1.38\times10^{-23}\ \text{J/K}$$

$$\upsilon_\text{sound} = 343\ \text{m/s} \qquad N_\text{A} = 6.022\times10^{23}\ \text{mol}^{-1}$$

General kinematics

$$\bar{v} = \frac{x_2 - x_1}{t_2 - t_1} = \frac{\Delta x}{\Delta t} \qquad \bar{a} = \frac{v_2 - v_1}{t_2 - t_1} = \frac{\Delta v}{\Delta t}$$

$$v = \lim_{\Delta t\to 0}\frac{\Delta x}{\Delta t} \qquad a = \lim_{\Delta t\to 0}\frac{\Delta v}{\Delta t}$$

One-dimensional motion with constant acceleration

$$x = x_0 + v_0\Delta t + \frac{1}{2}a\Delta t^2 \qquad v = v_0 + a\Delta t \qquad v^2 - v_0^2 = 2a\left(x - x_0\right) \qquad \bar{v} = \frac{\upsilon + \upsilon_0}{2}$$

$$x = x_o + \tfrac{1}{2}\left(v_o + v\right)\Delta t$$

Two-dimensional motion with constant acceleration

$$x = x_0 + v_{0x}t + \frac{1}{2}a_x\Delta t^2 \qquad v_x = v_{0x} + a_x\Delta t \qquad v_x^2 - v_{0x}^2 = 2a_x\left(x - x_0\right) \qquad \overline{v}_x = \frac{v_x + v_{0x}}{2}$$

$$x = x_o + \tfrac{1}{2}\left(v_{ox} + v_x\right)\Delta t$$

$$y = y_0 + v_{0y}\Delta t + \frac{1}{2}a_y\Delta t^2 \qquad v_y = v_{0y} + a_y\Delta t \qquad v_y^2 - v_{0y}^2 = 2a_y\left(y - y_0\right) \qquad \overline{v}_y = \frac{v_y + v_{0y}}{2}$$

$$y = y_o + \tfrac{1}{2}\left(v_{oy} + v_y\right)\Delta t$$

Projectile motion

$$x = x_0 + v_x\Delta t \qquad v_x = \text{constant}$$

$$y = y_0 + v_{0y}t - \frac{1}{2}g\Delta t^2 \qquad v_y = v_{0y} - g\Delta t \qquad v_y^2 - v_{0y}^2 = -2g\left(y - y_0\right) \qquad \overline{v}_y = \frac{v_y + v_{0y}}{2}$$

Forces

$$\vec{F}_{AB} = -\vec{F}_{BA} \qquad \sum \vec{F} = m\vec{a} \qquad \vec{F}_G(\equiv \vec{W}) = m\vec{g} \qquad F_{fr} \le \mu_s F_N \qquad F_{fr} = \mu_k F_N$$

$$F_S = -k\Delta x \qquad F_G = G\frac{m_1 m_2}{r^2}$$

Circular motion

$$\omega = \frac{\Delta\theta}{\Delta t} \qquad \alpha = \frac{\Delta\omega}{\Delta t} \qquad s = r\theta \qquad v_{\tan} = r\omega \qquad a_{\tan} = r\alpha$$

$$a_C = \frac{v^2}{r} = r\omega^2 \qquad a = \sqrt{a_C^2 + a_{\tan}^2} \qquad \text{Constant } \omega\text{: } T = \frac{1}{f} = \frac{2\pi}{\omega}$$

Constant α: $\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2 \qquad \omega = \omega_0 + \alpha t \qquad \omega^2 - \omega_0^2 = 2\alpha\Delta\theta \qquad \overline{\omega} = \frac{\omega + \omega_0}{2}$

Relative motion

$$\vec{r}_{\text{A relative to C}} = \vec{r}_{\text{A relative to B}} + \vec{r}_{\text{B relative to C}} \qquad \vec{r}_{\text{A relative to B}} = -\vec{r}_{B\text{ relative to A}}$$

$$\vec{v}_{\text{A relative to C}} = \vec{v}_{\text{A relative to B}} + \vec{v}_{\text{B relative to C}} \qquad \vec{v}_{\text{A relative to B}} = -\vec{v}_{\text{B relative to A}}$$

$$\vec{a}_{\text{A relative to C}} = \vec{a}_{\text{A relative to B}} + \vec{a}_{\text{B relative to C}} \qquad \vec{a}_{\text{A relative to B}} = -\vec{a}_{\text{B relative to A}}$$

Work and energy

$$W = Fd\cos\theta \qquad KE = \frac{1}{2}mv^2 = \frac{p^2}{2m} \qquad W_{\text{net}} = \Delta KE = \frac{1}{2}mv_f^2 - \frac{1}{2}mv_0^2$$

$$PE_{elastic} = \frac{1}{2}kx^2 \qquad PE_{grav} = mgy \qquad W_{\text{conservative}} = -\Delta PE$$

$$E = KE + PE \qquad \Delta E = \Delta KE + \Delta PE = W_{\text{non-conservative}} \qquad \overline{P} = \frac{W}{t}$$

Momentum, impulse. Systems of particles.

$$\vec{p} = m\vec{v} \qquad \sum \vec{F} = \frac{\Delta\vec{p}}{\Delta t}$$

$$\vec{r}_{\text{CM}} = \frac{\sum(m\vec{r})}{\sum m} \qquad \vec{v}_{\text{CM}} = \frac{\sum(m\vec{v})}{\sum m} \qquad \vec{a}_{\text{CM}} = \frac{\sum(m\vec{a})}{\sum m}$$

$$\vec{p}_{\text{total}} = \sum \vec{p} = \sum(m\vec{v}) = m_{\text{total}}\vec{v}_{\text{CM}} \qquad \vec{F}_{\text{net, external}} = \frac{\Delta\vec{p}_{\text{total}}}{\Delta t} = m_{\text{total}}\vec{a}_{\text{CM}} \qquad \left(\text{When } \vec{F}_{\text{net, external}} = 0,\ \vec{p}_{\text{total,i}} = \vec{p}_{\text{total,f}}\right)$$

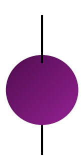
$$\left(\text{elastic collision in one dimension: } v_{1,\text{i}} - v_{2,\text{i}} = -\left(v_{1,\text{f}} - v_{2,\text{f}}\right)\right)$$

Rigid-body motion

$$KE = \frac{1}{2}Mv_{\text{CM}}^2 + \frac{1}{2}I_{\text{CM}}\omega^2 \qquad KE = \frac{1}{2}I\omega^2 \qquad \tau = rF\sin\theta = r_\perp F = rF_\perp \qquad L = rp\sin\theta = r_\perp p = rp_\perp$$

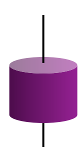
$$I = \sum mr^2 \qquad \sum\tau = \frac{\Delta L}{\Delta t}$$

(For rotation about a fixed axis: $\sum\tau = I\alpha$ and $L = I\omega$)

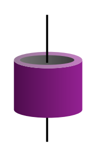


$$I_{\text{solid sphere}} = \frac{2}{5}MR^2$$

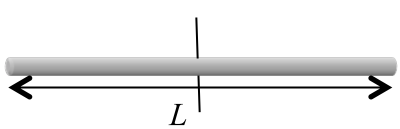
$$I_{\text{hollow sphere}} = \frac{2}{3}MR^2$$



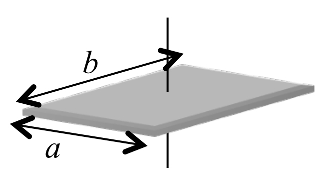
$$I_{\text{solid cylinder}} = \frac{1}{2}MR^2$$



$$I_{\text{hollow cylinder}} = \frac{1}{2}M\left(R_1^2 + R_2^2\right)$$



$$I_{\text{rod}} = \frac{1}{12}ML^2$$



$$I_{\text{rectangle}} = \frac{1}{12}M\left(L^2 + W^2\right)$$

Fluids

$$\rho = \frac{m}{V} \qquad P = \frac{F}{A} \qquad P = P_0 + \rho g \Delta h \qquad \rho A v = \text{constant} \qquad P + \frac{1}{2}\rho v^2 + \rho g y = \text{constant}$$

Gravitation

$$\vec{F} = G\frac{m_1 m_2}{r^2} \qquad PE_{grav} = -G\frac{Mm}{r} \qquad g = G\frac{m_E}{r_E^2} \qquad \upsilon_{\text{circular orbit}} = \sqrt{\frac{GM}{r}}$$

$$\frac{T^2}{r^3} = \frac{4\pi^2}{GM} \qquad g = 9.80\ \text{m/s}^2 \qquad G = 6.67\times10^{-11}\ \text{Nm}^2/\text{kg}^2$$

$$M_\text{E} = 5.98\times10^{24}\ \text{kg} \qquad R_\text{E} = 6.38\times10^{6}\ \text{m}$$

Simple harmonic motion

$$x = A\cos(\omega t) \qquad \upsilon = -A\omega\sin(\omega t) = -v_\text{max}\sin(\omega t) \qquad a = -A\omega^2\cos(\omega t) = -a_\text{max}\cos(\omega t)$$

$$T = \frac{1}{f} = \frac{2\pi}{\omega} \qquad \omega = \sqrt{\frac{k}{m}} \qquad T = 2\pi\sqrt{\frac{L}{g}}$$

Mechanical waves

$$v = \lambda f \qquad \omega = 2\pi f \qquad f = \frac{1}{T} \qquad v = \sqrt{\frac{F_T}{m/L}} \qquad I = \frac{P}{4\pi r^2}$$

$$d_1 - d_2 = n\lambda \quad n = 0,1,2,3,\ldots \qquad d_1 - d_2 = \lambda\left(n + \frac{1}{2}\right) \quad n = 0,1,2,3,\ldots$$

$$f_n = \frac{v}{\lambda_n} = n\left(\frac{v}{2L}\right) \quad n = 1,2,3,\ldots \qquad f_n = \frac{v}{\lambda_n} = n\left(\frac{v}{4L}\right) \quad n = 1,3,5,7\ldots$$

Sound

$$I = \frac{P}{4\pi r^2} \qquad \beta = (10\ \text{dB})\log\frac{I}{I_0} \qquad I_0 = 1.0\times10^{-12}\ \text{W/m}^2$$

$$f_\text{beat} = f_a - f_b \qquad f_{obs} = \frac{\upsilon_{sound} \pm \upsilon_{obs}}{\upsilon_{sound} \mp \upsilon_{source}} f_{source} \qquad v_\text{sound} = 343\ \text{m/s}$$

Temperature and heat

$$T_K = T_C + 273.15 \text{ K} \qquad T_F = \frac{9}{5}T_C + 32 \text{ F} \qquad \Delta L = \alpha L_0 \Delta T \qquad \Delta V = \beta V_0 \Delta T$$

$$Q = mc\Delta T \qquad Q = mL$$

$$\frac{Q}{t} = kA\frac{T_H - T_C}{l} \qquad \frac{\Delta Q}{\Delta t} = Ae\sigma\left(T_{\text{object}}^4 - T_{\text{surrounding}}^4\right) \qquad \sigma = 5.67\times10^{-8}\ \text{W}/\left(\text{m}^2\cdot\text{K}^4\right)$$

Ideal gas

$$PV = nRT = NkT \qquad n = \frac{N}{N_A} \qquad N_A = 6.022\times10^{23}\ \text{mol}^{-1}$$

$$R = 8.314\ \frac{\text{J}}{\text{mol}\cdot\text{K}} \qquad k = \frac{R}{N_A} = 1.38\times10^{-23}\ \text{J/K}$$

$$\overline{KE} = \frac{1}{2}m\overline{v^2} = \frac{3}{2}kRT \qquad \upsilon_{rms} = \sqrt{\frac{3kT}{m}} \qquad U = \frac{3}{2}nRT \text{ (monatomic gas)}$$

Thermodynamics

$$\Delta U = Q - W \qquad W = P\Delta V \qquad W = nRT\ln\left(\frac{V_f}{V_i}\right)$$

$$e = \frac{W}{Q_H} = 1 - \frac{Q_L}{Q_H} \qquad COP_{\text{refrigerator}} = \frac{Q_L}{W} \qquad COP_{\text{heat pump}} = \frac{Q_H}{W} \qquad e_{ideal} = 1 - \frac{T_L}{T_H}$$

$$\Delta S = \frac{Q}{T} \qquad \Delta S > 0$$