Formula Sheet for PHY111 (Summer 2023)

Principles of Physics-I

FACULTY: Akiful Islam (AZW)

SECTIONS: **14** (UB10104)
35 (UB41403)
36 (UB41403)

DISCLAIMER: I hope this work won't be used as a means of slacking off and just banally memorizing them. Do so, and it will catch up to You one way or another. Please don't mistake it for a mode of cheating.

CONTENTS

1 Translational Kinematics

1.1 Position Vector

$$\vec{r} = x\hat{i} + y\hat{j} + z\hat{k} \tag{1.1}$$

1.2 Displacement Vector

$$\Delta\vec{r} = \vec{r}_2 - \vec{r}_1 \tag{1.2}$$

1.3 Average Velocity

$$v_{\text{avg}} = \frac{\Delta\vec{r}}{\Delta t} \tag{1.3}$$

1.4 Instantaneous Velocity/Speed

$$v = \lim_{\Delta t \to 0} \frac{\Delta r}{\Delta t} = \frac{\mathrm{d}r}{\mathrm{d}t} \tag{1.4}$$

$$\vec{v} = \frac{\mathrm{d}\vec{r}}{\mathrm{d}t} = v_x\hat{i} + v_y\hat{j} + v_z\hat{k} = \frac{\mathrm{d}x}{\mathrm{d}t}\hat{i} + \frac{\mathrm{d}y}{\mathrm{d}t}\hat{j} + \frac{\mathrm{d}z}{\mathrm{d}t}\hat{k} \tag{1.4.2}$$

1.5 Average Acceleration

$$a_{\text{avg}} = \frac{\Delta v}{\Delta t} \tag{1.5}$$

1.6 Instantaneous Acceleration

$$a = \frac{\mathrm{d}v}{\mathrm{d}t} = \frac{\mathrm{d}^2x}{\mathrm{d}t^2} \tag{1.6}$$

$$\vec{a} = \frac{\mathrm{d}\vec{v}}{\mathrm{d}t} = a_x\hat{i} + a_y\hat{j} + a_z\hat{k} = \frac{\mathrm{d}v_x}{\mathrm{d}t}\hat{i} + \frac{\mathrm{d}v_y}{\mathrm{d}t}\hat{j} + \frac{\mathrm{d}v_z}{\mathrm{d}t}\hat{k} \tag{1.6.2}$$

1.7 Primitive Laws of Translational Motion (a = constant)

$$\vec{v} = \vec{v}_0 + \vec{a}t \tag{1.7}$$

$$\vec{r} - \vec{r}_0 = \frac{1}{2}(\vec{v}_0 + \vec{v})t \tag{1.7.2}$$

$$\vec{r} - \vec{r}_0 = \vec{v}_0 t + \frac{1}{2}\vec{a}t^2 \tag{1.7.3}$$

$$\vec{v}^2 = \vec{v}_0^2 + 2\vec{a}(\vec{r} - \vec{r}_0) \tag{1.7.4}$$

1.8 Uniform Circular Motion

Tangential/Parallel acceleration

$$a_{\parallel} = \frac{dv}{dt} \tag{1.8}$$

Radial/Perpendicular/Centripetal acceleration

$$a_c = \frac{v^2}{R} \tag{1.8.2}$$

Linear Speed of circular motion

$$v = \frac{2\pi R}{T} \tag{1.8.3}$$

Period of a circular motion

$$T = \frac{2\pi R}{v} \tag{1.8.4}$$

1.9 Vertical Projection

Height at any point of the trajectory

$$y = y_0 + v_0 t - \frac{gt^2}{2} \tag{1.9}$$

Vertical speed at any instant in time

$$v_y = -gt \tag{1.9.2}$$

1.10 Slant Projection

Height at any point of the trajectory

$$y = x \tan \alpha_0 - \frac{gx^2}{2(v_0 \cos \alpha_0)^2} \tag{1.10}$$

Horizontal component of initial velocity

$$v_x = v_0 \cos \alpha_0 = \text{constant} \tag{1.10.2}$$

Vertical velocity at maximum height

$$v_y = 0 \tag{1.10.3}$$

Vertical speed at any instant in time

$$v_y = v_0 \sin \alpha_0 - gt \tag{1.10.4}$$

1.11 Everything about Projectile

Horizontal Component of the Initial Velocity

$$v_x = v_0 \cos \alpha_0 \tag{1.11}$$

Vertical Component of the Initial Velocity

$$v_{0y} = v_0 \sin \alpha_0 \tag{1.11.2}$$

Time elapsed to reach Maximum Height

$$t_{\text{max}} = \frac{v_{0y}}{g} = \frac{v_0 \sin \alpha_0}{g} \tag{1.11.3}$$

Time elapsed for the Projectile Range (Symmetric Motion/No Air Resistance)

$$t_{\text{range}} = 2t_{\text{max}} = 2\frac{v_{0y}}{g} = \frac{2v_0 \sin \alpha_0}{g} \tag{1.11.4}$$

Maximum height of a Projectile from ground

$$h_{\text{max}} = v_{0y} t_{\text{max}} = \frac{(v_0 \sin \alpha_0)^2}{2g} \tag{1.11.5}$$

Horizontal Range at any time t

$$l = v_x t \tag{1.11.6}$$

Maximum Horizontal Range (Only works for the same height)

$$R = v_x t_{\text{range}} = 2v_0 \cos \alpha_0 \frac{v_{0y}}{g} = \frac{v_0^2 \sin 2\alpha_0}{g} \tag{1.11.7}$$

2 Translational Dynamics

2.1 Newton's 2$^{\text{nd}}$ Law of Motion (For Inertial System)

$$\sum F = m\vec{a} \tag{2.1}$$

$$\sum F_x = ma_x \tag{2.1.2}$$

$$\sum F_y = ma_y \tag{2.1.3}$$
$$\sum F_z = ma_z \tag{2.1.4}$$

2.2 Friction Force

Static Friction Force

$$f_s^{\max} = \mu_s N \tag{2.2}$$

Kinetic Friction Force

$$f_k = \mu_k N \tag{2.2.2}$$

Speed on a level road with friction (No banking)

$$v = \sqrt{g\mu_s R} \tag{2.2.3}$$

Coefficient of friction on a banked road with friction (No banking)

$$\mu_s = \frac{v^2}{gR} \tag{2.2.4}$$

Banking angle of a road without friction

$$\theta = \tan^{-1}\left(\frac{a_{\text{rad}}}{g}\right) = \tan^{-1}\left(\frac{v^2}{gR}\right) \tag{2.2.5}$$

Coefficient of static friction of banked road

$$\mu_s = \frac{v^2 - gR\tan\theta}{v^2\tan\theta + gR} \tag{2.2.6}$$

Banking angle of a road with friction

$$\theta = \tan^{-1}\left(\frac{v^2 - \mu_s gR}{\mu_s v^2 + gR}\right) \tag{2.2.7}$$

Maximum speed on a banked road with friction

$$v_{\max} = \sqrt{gR \times \frac{\mu_s + \tan\theta}{1 - \mu_s\tan\theta}} \tag{2.2.8}$$

Minimum speed on a banked road with friction

$$v_{\min} = \sqrt{gR \times \frac{\mu_s - \tan\theta}{1 + \mu_s\tan\theta}} \tag{2.2.9}$$

3 Work, Energy, Power

3.1 Everything about Work

Work done by a constant force

$$W = \vec{F} \cdot \vec{s} \tag{3.1}$$

Work done by a variable force

$$W = \int \vec{F} \cdot \vec{r}\, d\vec{r} \tag{3.1.2}$$

$$W_s = \vec{F} \cdot \vec{r} = \int_{x_i}^{x_f} F_x(x)dx + \int_{y_i}^{y_f} F_y(x)dy + \int_{z_i}^{z_f} F_z(x)dz \tag{3.1.3}$$

Net work done (on a loop) by a Conservative force

$$\Delta W = 0 \tag{3.1.4}$$

Net work done (on a loop) by a Non-Conservative force

$$\Delta W \neq 0 \tag{3.1.5}$$

3.2 Everything about Energy

Kinetic Energy

$$E_k = \frac{1}{2}mv^2 \tag{3.2}$$

Work-Energy Theorem

$$W = \Delta E = \vec{F} \cdot \vec{s} = Fs\ \cos\theta \tag{3.2.2}$$

$W_g \rightarrow$ Gravitational Force

$$W_g = mg\Delta y = -\Delta E_p \tag{3.2.3}$$

Potential Energy

$$\Delta E_p = U = -W = -\int_{r_i}^{r_f} F(r)dr \tag{3.2.4}$$

where

$$F(r) = -\frac{\mathrm{d}E_p(r)}{\mathrm{d}r} \tag{3.2.5}$$

$\vec{F}_s \rightarrow$ Variable force; $k \rightarrow$ Elastic (Spring) constant

$$\vec{F}_{\text{elas}} = -k\vec{d} \tag{3.2.6}$$

$$W_{\text{elas}} = \frac{1}{2}kx_f^2 - \frac{1}{2}kx_i^2 \tag{3.2.7}$$

Mechanical Energy

$$E_{\text{mech}} = \Delta E_k + \Delta E_p = E + U \tag{3.2.8}$$

3.3 Everything about Power

Average Power

$$P_{\text{avg}} = \frac{W}{\Delta t} \tag{3.3}$$

Instantaneous Power

$$P = \frac{\mathrm{d}W}{\mathrm{d}t} = \vec{F}\vec{v} \tag{3.3.2}$$

4 Rotational Kinematics

4.1 Bare Essential Variables

All angles must be calculated in Radian

Angular Position

$$\theta = \frac{s}{r} \tag{4.1}$$

Angular Displacement

$$\Delta\theta = \theta_f - \theta_i \tag{4.1.2}$$

Average Angular Velocity

$$\omega_{\text{avg}} = \frac{\Delta\theta}{\Delta t} \tag{4.1.3}$$

Instantaneous Angular Velocity

$$\omega = \lim_{\Delta t \to 0} \frac{\Delta\theta}{\Delta t} = \frac{\mathrm{d}\theta}{\mathrm{d}t} \tag{4.1.4}$$

Average Angular Acceleration

$$\alpha_{\text{avg}} = \frac{\Delta\omega}{\Delta t} \tag{4.1.5}$$

Instantaneous Angular Acceleration

$$\alpha = \lim_{\Delta t \to 0} \frac{\Delta\omega}{\Delta t} = \frac{\mathrm{d}\omega}{\mathrm{d}t} \tag{4.1.6}$$

$s \rightarrow \theta$: Relating circular displacement to angular position

$$s = \theta r \tag{4.1.7}$$

$v \rightarrow \omega$: Relating angular speed to linear speed

$$v = \omega r \tag{4.1.8}$$

Vector form of angular velocity

$$\vec{v} = \vec{\omega} \times \vec{r} \tag{4.1.9}$$

$a \rightarrow \alpha$: Relating angular acceleration to linear acceleration

$$a = \alpha r \tag{4.1.10}$$

Vector form of angular acceleration

$$\vec{a} = \vec{\alpha} \times \vec{r} + \vec{\omega} \times \vec{v} \tag{4.1.11}$$

Period of a Rotational motion

$$T = \frac{\pi r}{v} = \frac{2\pi}{\omega} \tag{4.1.12}$$

Centripetal Acceleration, $a_{\text{rad}} \rightarrow$ radial component of a

$$a_{\text{rad}} = \frac{v_2}{r} = \omega^2 r \tag{4.1.13}$$

$I \rightarrow$ Moment of Inertia

$$E_k = \sum \frac{1}{2} m_i v_i = \left(\sum \frac{1}{2} m_i r_i^2 \right) \omega^2 = \frac{1}{2} I \omega^2 \tag{4.1.14}$$

$$I = \sum m_i r_i^2 = \int r^2 dm \tag{4.1.15}$$

Torque

$$\vec{\tau} = \vec{r} \times \vec{F} \tag{4.1.16}$$

$r \rightarrow$ length of the moment arm—perpendicular distance from the center of rotation to the action line; $F_\perp \rightarrow$ Perpendicular component of force; $r_\perp \rightarrow$ Perpendicular component of the moment arm length, the magnitude of total force

$$\tau = (r)(F \sin\phi) = rF_\perp = (r \sin\phi)(F) = (r_\perp)(F) \tag{4.1.17}$$

Angular Momentum

$$\vec{L} = \vec{r} \times \vec{v} \tag{4.1.18}$$

$r \rightarrow$ length of the moment arm—perpendicular distance from the center of rotation to the action line; $F_\perp \rightarrow$ Perpendicular component of force

$$L = (r)(mv \sin\phi) = rmv_\perp \tag{4.1.19}$$

Conservation of Angular Momentum

$$\text{If } \sum \vec{\tau} = 0, \quad \Delta\vec{L} = 0 \tag{4.1.20}$$

$$\vec{L} = \text{constant} \tag{4.1.21}$$

where

$$\tau = I\alpha \tag{4.1.22}$$

With no net torque, the angular momentum of an isolated system remains constant

When orbit size changes of a circular motion

$$I_{\text{initial}}\,\omega_{\text{initial}} = I_{\text{final}}\,\omega_{\text{final}} \tag{4.1.23}$$

With r and ω, You may wanna use

$$r^2_{\text{initial}}\,\omega_{\text{initial}} = r^2_{\text{final}}\,\omega_{\text{final}} \tag{4.1.24}$$

$$\omega_{\text{final}} = \left(\frac{r_{\text{initial}}}{r_{\text{final}}}\right)^2 \omega_{\text{initial}} \tag{4.1.25}$$

With r and v, You may wanna use

$$v_{\text{initial}}\,r_{\text{initial}} = v_{\text{final}}\,r_{\text{final}} \tag{4.1.26}$$

$$v_{\text{final}} = \left(\frac{r_{\text{initial}}}{r_{\text{final}}}\right) v_{\text{initial}} \tag{4.1.27}$$

4.2 Primitive Laws of Rotational Motion (α = constant)

$$\omega = \omega_0 + \vec{\alpha}t \tag{4.2}$$

$$\theta - \theta_0 = \frac{1}{2}(\vec{\omega}_0 + \vec{\omega})t \tag{4.2.2}$$

$$\theta - \theta_0 = \vec{\omega}_0 t + \frac{1}{2}\vec{\alpha}t^2 \tag{4.2.3}$$

$$\vec{\omega}^2 = \vec{\omega}_0^2 + 2\vec{\alpha}(\theta - \theta_0) \tag{4.2.4}$$

5 Rotational Dynamics

5.1 Newton's 2nd Law of Motion (For Inertial System)

$$\sum \vec{\tau} = I\vec{\alpha} \tag{5.1}$$

$$\sum \tau_x = I\alpha_x \tag{5.1.2}$$

$$\sum \tau_y = I\alpha_y \tag{5.1.3}$$

$$\sum \tau_z = I\alpha_z \tag{5.1.4}$$

5.2 Work and energy in Rotation

Rotational Kinetic Energy

$$E_k = \frac{1}{2}I\omega^2 \tag{5.2}$$

Rotational Work done

$$W = \int_{\theta_{\text{initial}}}^{\theta_{\text{final}}} \tau d\theta \tag{5.2.2}$$

Rotational Work-Energy Theorem

$$\Delta E_k = \frac{1}{2}I(\Delta\omega)^2 = \int_{\theta_{\text{initial}}}^{\theta_{\text{final}}} \tau d\theta \tag{5.2.3}$$

For a constant torque τ

$$\Delta E_k = \tau(\theta_{\text{final}} - \theta_{\text{initial}}) \tag{5.2.4}$$

Total Kinetic Energy of a body in both translational and rotational motion

$$E_k = \frac{1}{2}I\omega^2 + \frac{1}{2}mv^2 \tag{5.2.5}$$

$$E_{\text{ rotational}} = \frac{1}{2}I\omega^2 \tag{5.2.6}$$

$$E_{\text{ translational}} = \frac{1}{2}mv^2 \tag{5.2.7}$$

Rotational Power

$$P = \tau\omega \tag{5.2.8}$$

6 Many Particle System and Rigid Bodies

6.1 Everything about a Many-Particle System

Center of Mass of n particle system

$$x_{\text{com}} = \frac{1}{M}\sum_{i=1}^{n} x_i m_i;\;\; y_{\text{com}} = \frac{1}{M}\sum_{i=1}^{n} y_i m_i;\;\; z_{\text{com}} = \frac{1}{M}\sum_{i=1}^{n} z_i m_i \tag{6.1}$$

Position of the center of mass of n particle system

$$\vec{r}_{\text{com}} = \hat{i}x_{\text{com}} + \hat{j}y_{\text{com}} + \hat{k}z_{\text{com}} \tag{6.1.2}$$

Velocity of the center of mass of n particle system

$$\vec{v}_{\text{com}} = \hat{i}\sum_{i=1}^{n} v_{xi}^{\text{com}} + \hat{j}\sum_{i=1}^{n} v_{yi}^{\text{com}} + \hat{k}\sum_{i=1}^{n} v_{zi}^{\text{com}} = \vec{v}_1 + \vec{v}_2 + \vec{v}_3 + \dots\;\dots + \vec{v}_n \tag{6.1.3}$$

Acceleration of the center of mass of n particle system

$$\vec{a}_{\text{com}} = \hat{i}\sum_{i=1}^{n} a_{xi}^{\text{com}} + \hat{j}\sum_{i=1}^{n} a_{yi}^{\text{com}} + \hat{k}\sum_{i=1}^{n} a_{zi}^{\text{com}} = \vec{a}_1 + \vec{a}_2 + \vec{a}_3 + \dots\;\dots + \vec{a}_n \tag{6.1.4}$$

Momentum of the center of mass of n particle system

$$\vec{p}_{\text{com}} = \hat{i}\sum_{i=1}^{n} m_i v_{xi}^{\text{com}} + \hat{j}\sum_{i=1}^{n} m_i v_{yi}^{\text{com}} + \hat{k}\sum_{i=1}^{n} m_i v_{zi}^{\text{com}} = \vec{p}_1 + \vec{p}_2 + \vec{p}_3 + \dots\;\dots + \vec{p}_n \tag{6.1.5}$$

Newton's 2$^{\text{nd}}$ law for a n particle system

$$\vec{F}_{\text{net}} = \sum_{i=1}^{n} \vec{F} = M\vec{a}_{\text{com}} = \frac{\mathrm{d}\vec{p}_{\text{com}}}{\mathrm{d}t} \tag{6.1.6}$$

6.2 Everything about a Rigid Body System

Center of Mass of a Rigid Body system

$$x_{\text{com}} = \frac{1}{M}\int x dm,\; y_{\text{com}} = \frac{1}{M}\int y dm,\; z_{\text{com}} = \frac{1}{M}\int z dm \tag{6.2}$$

Position of the center of mass of a Rigid Body system

$$\vec{r}_{\text{com}} = \frac{1}{M}\left(\hat{i}\int x dm + \hat{j}\int y dm + \hat{k}\int z dm\right) \tag{6.2.2}$$

Velocity of the center of mass of a Rigid Body system

$$\vec{v}_{\text{com}} = \hat{i}v_x + \hat{j}v_y + \hat{k}v_z \tag{6.2.3}$$

Acceleration of the center of mass of a Rigid Body system

$$\vec{a}_{\text{com}} = \hat{i}a_x + \hat{j}a_y + \hat{k}a_z \tag{6.2.4}$$

Momentum of the center of mass of a Rigid Body system

$$\vec{p}_{\text{com}} = \hat{i}p_x + \hat{j}p_y + \hat{k}p_z \tag{6.2.5}$$

Newton's 2$^{\text{nd}}$ law for a n particle system

$$\vec{F}_{\text{net}} = \int d\vec{F} = M\vec{a}_{\text{com}} = \frac{\mathrm{d}\vec{p}_{\text{com}}}{\mathrm{d}t} \tag{6.2.6}$$

6.3 Momentum related Stuff

Linear Momentum

$$\vec{p} = m\vec{v} \tag{6.3}$$

Impulse of a Force

$$\vec{J} = \Delta\vec{p} = \vec{F_{\text{avg}}} = \int_{t_i}^{t_f} \vec{F}(t)dt\Delta t \tag{6.3.2}$$

Conservation of Linear Momentum

$$\text{If } \sum \vec{F} = 0, \quad \Delta\vec{p} = 0 \tag{6.3.3}$$

$$\vec{p} = \text{constant} \tag{6.3.4}$$

With no net force, the linear momentum of an isolated system remains constant

6.4 1D Collision

Elastic Collision

$$m_1\vec{v}_{1i} + m_2\vec{v}_{2i} = m_1\vec{v}_{1f} + m_2\vec{v}_{2f} \quad \text{(Conservation of Linear Momentum)} \tag{6.4}$$

$$\frac{1}{2}m_1v_{1i}^2 + \frac{1}{2}m_2v_{2i}^2 = \frac{1}{2}m_1v_{1f}^2 + \frac{1}{2}m_2v_{2f}^2 \quad \text{(Conservation of Energy)} \tag{6.4.2}$$

where

$$\vec{v}_{1f} = \frac{m_1 - m_2}{m_1 + m_2}\vec{v}_{1i} + \frac{2m_2}{m_1 + m_2}\vec{v}_{2i} \tag{6.4.3}$$

$$\vec{v}_{2f} = \frac{2m_1}{m_1 + m_2}\vec{v}_{1i} + \frac{m_2 - m_1}{m_1 + m_2}\vec{v}_{2i} \tag{6.4.4}$$

Inelastic Collision

$$m_1\vec{v}_{1i} + m_2\vec{v}_{2i} = (m_1 + m_2)\vec{v} \quad \text{(Conservation of Linear Momentum)} \tag{6.4.5}$$

6.5 2D Collision

$\alpha \rightarrow$ Initial Angle; $\theta \rightarrow$ Recoil Angle

x-axis analysis

$$m_1v_{1i}\cos\alpha_1 + m_2v_{2i}\cos\alpha_2 = m_1v_{1f}\cos\theta_1 + m_2v_{2f}\cos\theta_2 \tag{6.5}$$

y-axis analysis

$$m_1v_{1i}\sin\alpha_1 + m_2v_{2i}\sin\alpha_2 = m_1v_{1f}\sin\theta_1 + m_2v_{2f}\sin\theta_2 \tag{6.5.2}$$

7 State of Equilibrium

7.1 Tranlational Equilibrium

Translational Equilibrium

$$\sum \vec{F}_{\text{net}} = 0 \tag{7.1}$$

3 constantraints on Force

$$\sum F_x = 0, \quad \sum F_y = 0, \quad \sum F_z = 0 \tag{7.1.2}$$

7.2 Rotational Equilibrium

Rotational Equilibrium

$$\sum \vec{\tau}_{\text{net}} = 0 \tag{7.2}$$

3 constantraints on Torque

$$\sum \tau_x = 0, \quad \sum \tau_y = 0, \quad \sum \tau_z = 0 \tag{7.2.2}$$

Total 6 constantraints for a complete equilibrium

$$\Delta\vec{p} = 0, \quad \text{and} \quad \Delta\vec{L} = 0 \tag{7.2.3}$$

8 Gravitation

8.1 Newton's law of Universal Gravitation

Force of gravity between two bodies

$$F = G\frac{m_1 m_2}{r^2} \tag{8.1}$$

where Universal constant of Gravitation

$$G = 6.673 \times 10^{-11}\, N\frac{m^2}{kg^2} \tag{8.1.2}$$

Gravitational acceleration due to an astronomical body of mass M and radius R

$$a_g = \frac{GM}{r^2} \tag{8.1.3}$$

Gravitational acceleration felt by a body

$$g = a_g - \omega^2 R \tag{8.1.4}$$

Vector form of the force of Gravity, $R \rightarrow$ distance between two bodies

$$\vec{F} = \frac{GMm}{R^3}\vec{R} = \frac{GMm}{R^2}\hat{R} \tag{8.1.5}$$

Gravitational Potential Energy

$$E_p = -\frac{GMm}{r} \tag{8.1.6}$$

8.2 Orbits and Gravitational Energies

Potential Energy of an orbit

$$E_p = -\frac{GMm}{r} \tag{8.2}$$

Kinetic Energy of an orbit

$$E_k = \frac{GMm}{2r} = -\frac{E_p}{2} \tag{8.2.2}$$

Mechanical Energy of an orbit

$$E = E_p + E_k = -\frac{GMm}{2r} \tag{8.2.3}$$

Escape Velocity

$$v = \sqrt{\frac{2GM}{R}} = \sqrt{2gR} \tag{8.2.4}$$

8.3 Kepler's Laws of Planetary Motion

Kepler's 1st Law: **Law of Orbits**: All planets move in elliptical orbits. They move around their host star in elliptical orbits with the star at one of the ellipse's foci.

Kepler's 2nd Law: **Law of Areas**: All planets move so that the line connecting it to the host star sweeps out equal areas at equal times.

$$\text{constant} = \frac{\mathrm{d}A}{\mathrm{d}t} = \frac{1}{2}a^2\omega = \frac{L}{2m} \tag{8.3}$$

A planet body speeds up as it gets closer to its host star, and slows down as it goes further

$$a_1^2\omega_1 = a_2^2\omega_2 = \text{constant} \tag{8.3.2}$$

Kepler's 3rd Law: **Law of Periods**: The square of the period of a planet is proportional to the cube of the semi-major axis of its orbit.

$$T^2 = \left(\frac{4\pi^2}{GM}\right)a^3 \tag{8.3.3}$$

The square of the orbital period of a planet is directly proportional to the cube of its orbit size